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THE FLUORSPAR DEPOSITS OF ST. LAWRENCE, NEWFOUNDLAND.[1]

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ABSTRACT.

Fluorspar from Newfoundland, eighth ranking producer of the world, comes entirely from the St. Lawrence district. Here pre-Cambrian lavas and pyroclastics, Cambrian sedimentary rocks, Ordovician (?) volcanic and sedimentary rocks, and a Paleozoic alaskite-granite comprise the bedrock.

Epithermal fluorite veins occupy steeply dipping fault fissures in granite, rhyolite porphyry, and lamprophyre. Eleven veins show walls bearing nearly horizontal striations; one vein bears only vertical striations; and the walls of three veins show both horizontal and vertical striations. The strikes of nearly all veins are within 45° of the normal to the walls of the elongated granite mass. Some veins are more than a mile long and contain numerous workable lenses. Veins are of two types: high-grade containing over 95 per cent CaF_2 and averaging about 5 feet thick, and lower grade containing about 75 per cent CaF_2 and averaging between 15 and 20 feet thick.

Sulphides, present in small quantities, include pyrite, chalcopyrite, sphalerite, and argentiferous galena. Non-metallic gangue minerals are quartz, calcite, and rarely barite. "Blastonite," a local name for material composed of microcrystalline quartz and brecciated fluorite, in some places forms as much as 10 per cent of a vein. A nodular type of fluorspar probably formed by alternate rotation of fragments of breccia and deposition of fluorite.

Regional zoning is shown by the distribution of barite and green fluorite. Barite shows a distinct zone of localization, and green fluorite predominates in veins both near the granite margins and farther from the granite body.

This district will undoubtedly occupy a still more prominent position among producers of fluorspar.

[1] Published with the permission of the Newfoundland Government Geologist.

INTRODUCTION.

St. Lawrence, a new and important source of fluorspar, is near the tip of the Burin Peninsula of southern Newfoundland (Fig. 1). Under the auspices of the Geological Survey of Newfoundland the writer spent the summers of 1939 and 1940 in mapping

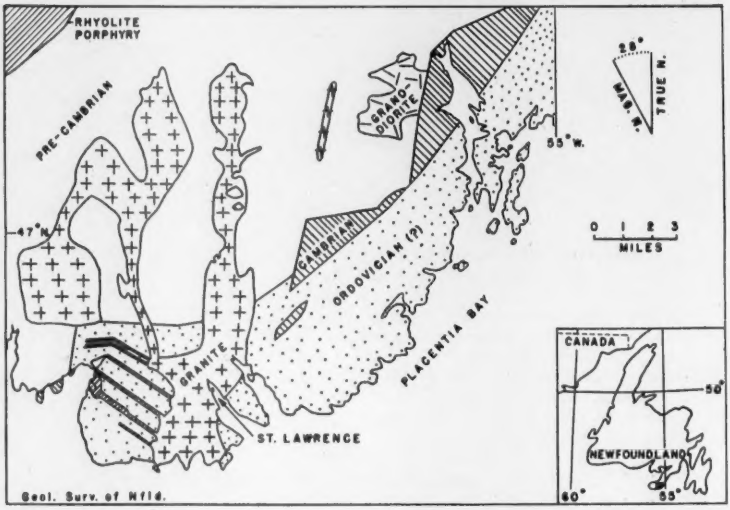

FIG. 1. Geologic map of the St. Lawrence area, Newfoundland.

about 300 square miles of the area and studying the fluorspar deposits in detail. Additional field studies were made during the summer of 1941 when the writer was employed by the Aluminum Company of Canada, Ltd.

AREAL GEOLOGY.

In the St. Lawrence area the bedded rocks are sedimentary and volcanic rocks of pre-Cambrian, Cambrian, and probable Ordovician age. Most of the Burin Peninsula north of St. Lawrence is underlain by pre-Cambrian lavas and pyroclastics, chiefly felsic types. Fossiliferous Lower and Middle Cambrian sandstones,

shales, and limestones are in faulted contact with the pre-Cambrian rocks, except at one locality west of St. Lawrence where the Cambrian beds unconformably overlie the older volcanic rocks. The rocks of probable Ordovician age consisting of argillite, slate, hornfels, massive and pillowed basalt, chert, and limestone lie chiefly in a belt along the southeast shore of the area.

The pre-Cambrian rocks were thrust faulted at high angles against the younger rocks. The axes of the major folds in the Cambrian and probable Ordovician rocks are parallel to these faults. The periods of folding and thrust faulting preceded the intrusion of the granite which contains most of the fluorspar veins.

The major intrusive rocks are: a body of pre-Cambrian granodiorite; sheet-like bodies of gabbro cutting the probable Ordovician rocks; and granite masses with associated rhyolite porphyry and lamprophyre bodies cutting pre-Cambrian, Cambrian, and probable Ordovician rocks.

ST. LAWRENCE GRANITE.

The St. Lawrence granite is the principal host rock of the fluorspar veins and is believed to be genetically related to the

FIG. 2. View northeast across the St. Lawrence granite toward hills of volcanics, showing fluorspar mine. Photo by C. K. Howse.

fluorite. The granite generally occupies lowlands, and the adjacent hills are composed of hornfels or volcanic rock (Fig. 2). The exposed granite is regarded as part of a batholithic mass

which has been only slightly exhumed by erosion. North of St. Lawrence several roof pendants of volcanic rocks and hornfels were found resting on the granite. The contacts of the granite dip away from the mass at a low angle except where they have been faulted.

The granite is chiefly a porphyritic alaskite variety composed essentially of quartz, orthoclase, and albite. The ferromagnesian minerals are scarce and comprise riebeckite and green biotite.

TABLE I.

Analysis			Norm			Mode		
	1	2.		1.	2.		1.	2.
SiO_2	78.43	79.07	Q	40.3	41.6	Qtz	38.1	37.0
Al_2O_3	11.25	11.65	Or	28.9	26.3	Perthite	41.0	31.8
Fe_2O_3	1.41	0.36	Ab	28.3	29.4	Albite	18.7	29.1
FeO	0.13	0.28	An	...	0.6	Mafics	...	2.1
MgO	0.01	0.16	C	0.5	0.9	Mt }	2.0	...
CaO	0.16	0.09	En	...	0.4	Hem }		
Na_2O	3.36	3.45	Fs	...	0.1	Fluorite	0.2	0.006
K_2O	4.90	4.46	Mt	0.1	0.5		100.0	100.0
H_2O+	0.13	0.25	Hm	1.4	...			
H_2O-	0.05	0.06	Il	0.2	0.2			
CO_2	0.01	...	F	0.3	...			
TiO_2	0.12	0.11						
P_2O_5	0.01	...		100.0	100.0			
F	0.15	...		Plagioclase				
MnO	trace	...		Ab_{100}	$Ab_{98}An_2$			
	100.12	99.94						
	.06 Less 0 = F							
	100.06							

1. Coarse-grained, porphyritic, miarolitic red alaskite granite from Iron Springs Mine, St. Lawrence Fluorspar District, Newfoundland. G. Kahan, analyst.

2. Medium-grained, slightly miarolitic red alaskite from Rencontre East area, Newfoundland. R. Folinsbee, analyst (39).

Fluorite is a common accessory mineral. Miarolitic cavities lined with euhedral crystals of quartz, orthoclase, albite, riebeckite, and fluorite are abundant. A chemical analysis shows that the granite has an unusually high silica and very low magnesia and lime content, and that the normative plagioclase is pure albite (Table 1, No. 1). For comparison an analysis is also presented of a

Paleozoic granite, mineralogically and texturally similar, from the Rencontre East area 50 miles north of St. Lawrence (39).[2]

Associated with the granite are numerous sills and dikes of rhyolite porphyry and lamprophyre. The mineral composition of the rhyolite porphyry is almost identical with that of the granite. At one locality a lamprophyre dike cuts a dike of rhyolite porphyry. Both the rhyolite porphyry and lamprophyre intrusives are earlier than the fluorite veins.

FLUORSPAR DEPOSITS.

A great variety of minerals is present in the St. Lawrence area, but fluorite is the only mineral being produced at the present time. Although Jukes (22) recorded the presence of fluorite at St. Lawrence one hundred years ago, fluorspar was not shipped until 1933. Murray and Howley (33, 34) record the early prospecting of some of the fluorite veins for their lead content. A paper by Howse (18) and another by Howse and Fischer (19) describe the fluorite veins and the more recent mining and milling activities at St. Lawrence.

Location. Commercial fluorspar veins have been found within an area of about 20 square miles west and north of St. Lawrence harbor. About 25 veins are of sufficient economic value or scientific interest to merit attention. The veins are from 0 to 6 miles from St. Lawrence harbor and at altitudes of 0 to 400 feet above sea level.

Host Rocks. Most fluorspar veins are in the batholith of alaskite granite, but sills of rhyolite porphyry west of the granite are also important host rocks. Some of the lamprophyre dikes which cut the granite carry fluorspar veins, but to date such deposits have been found to be of low grade and small size. In general, the adjacent hornfels or slate is considered to be a poor host rock for fluorspar veins, since only small, highly lenticular veins are known to cut this rock.

Although the host rocks show various kinds of alteration by the mineralizing solutions, the most widespread type is fluoritiza-

[2] Numbers in parentheses refer to bibliography.

tion. Fluorite commonly cements and replaces fragments of the brecciated rock beyond the walls of the veins, in places to such an extent that several additional feet of workable fluorspar are formed. This fluorite is nearly always a deep purple color. Sericitization and silicification have locally altered the wall rock of some veins in granite and rhyolite porphyry. Where hornfels or slate form the country rock of a vein, they are commonly bleached from dark green or black to light green. Wall rock of rhyolite porphyry in places shows bleaching from pink to tan or gray.

Types and Patterns of Veins. All fluorspar veins that were studied occupy fault fissures in the various host rocks. The striated hanging and foot walls were shattered to such an extent that zones of coarse breccia and microbreccia as much as 3 feet thick are common. Where such zones of breccia are partially replaced by fluorite, the deposit may be in part of replacement origin. The dominant vein-forming process, however, was one of repeated faulting and fissure filling. As a result the veins pinch and swell markedly both horizontally and vertically. The thickness of the veins ranges from a few inches to more than 50 feet, but not all of such great width may be commercial fluorspar. The average thickness of the higher grade veins is between 4 and 5 feet and that of the lower grade veins is between 15 and 20 feet. Several veins show fluorspar mineralization for a length of more than one mile, and no vein has been followed to its terminations. In many of the veins several distinct lenses of workable fluorspar have been developed along the strike.

Most veins dip from 70 to 90 degrees. Striations on the walls were recorded as pitching less than 30 degrees for 14 of 15 veins. The angle of pitch as used here was measured on the plane of the slickensided surface. The walls of other veins bear nearly vertical striations, and normal faulting is indicated. Eleven veins show walls bearing nearly horizontal striations; one vein bears only vertical striations; and the walls of three veins show both horizontal and vertical striations. In summary, most fluorspar

veins in the St. Lawrence district occupy fault fissures formed by horizontal shear, and a few veins occupy normal faults.

An analysis of the strikes of the veins shows a definite relation between vein trends and the elongation of the St. Lawrence granite batholith (Fig. 3). All but 6 veins strike within 45 degrees of

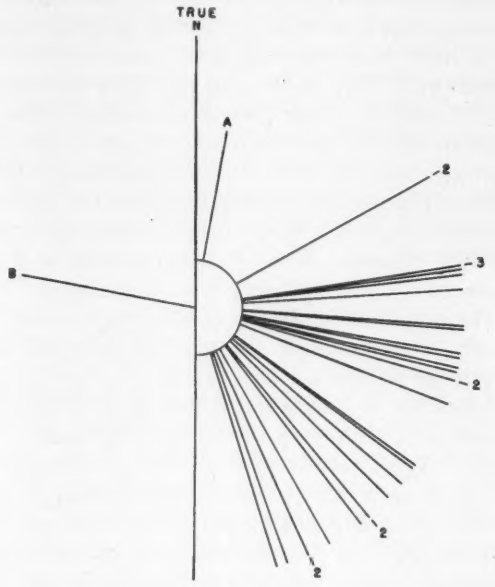

FIG. 3. Diagram showing the distribution of the strikes of fluorspar veins, St. Lawrence district. The numbers indicate more than one vein with this strike. Line A represents the trend of the long axis of the St. Lawrence granite, and line B, the normal to the long axis.

the trend of a line normal to the long axis of the granite. A decided concentration of the strikes of veins exists, therefore, in a zone approximately normal to the side walls of the granite mass as now exposed.

A marked relation between the strike of some veins and the type of mineralization also is evident. Five veins striking within a

zone ranging from N25°W to N45°W are typically lower grade than many other veins in the district. Although they are characterized by a greater quantity of calcite and quartz than normal, several of these veins are notable for their great length and thickness.

In the area immediately west of the St. Lawrence granite a distinct vein pattern is present. Almost all veins here strike from N50°W to N60°W and the walls bear horizontal striations. In the northeast walls of the main veins, small fluorspar veins branch out from the main vein at acute angles opening southeast. Along the northwest walls the main veins and branch veins form acute angles opening northwest. This fracture pattern, substantiated by other field evidence, is believed to indicate that the northeast wall moved northwestward relative to the southwest wall.

Mineralogy. Fluorite of the following colors has been observed at St. Lawrence: yellow, red, gray, blue, purple, green, pink, and white. The causes of the various colors are not known. Some of the fluorite is red because of included blebs of hematite and thin films of hematite between fine layers of fluorite. Some specimens of nearly colorless or faintly tinted fluorite show spherical and irregular patches of deep purple color, generally near the corners of cubes and aligned parallel to the octahedral cleavage. Some cubes of various colors have a film of purple fluorite on the outer surface. Such localization of the purple spots and films suggests that access to solutions or the atmosphere may be a prerequisite for their formation. Bastin (3, p. 42) describes purple halos in fluorite around exposed crystals of pyrite and chalcopyrite and concludes that exposure to air or to the liquids in the vugs was essential to the development of the purple halos.

The cube is by far the most abundant crystal form of fluorite in this district. The cubes range in size from a fraction of an inch to more than 18 inches on an edge. The larger cubes are generally composed of smaller cubes arranged in parallel or subparallel growths. Some cubes are grouped in parallel position to form a pseudo-octahedron. The octahedron is the usual crystal form of the green fluorite found chiefly in veins west of the St.

Lawrence granite. Some of this green fluorite shows a coarse internal fibrous structure. Octahedral fluorite is often considered to be earlier than cubic fluorite (23, 11), but at St. Lawrence it is both earlier and later than the cubic variety. Although no simple dodecahedra or tetrahexahedra were observed, specimens showing the truncation or bevelling of the cubes by dodecahedra, tetrahexahedra, or octahedra are not rare.

All varieties of fluorite were tested for fluorescence under ultraviolet light from a mercury vapor lamp. Nearly all specimens are negative, but the green octahedral variety of fluorite found west of the granite shows an especially strong blue fluorescence.

Sulphide minerals in the fluorite veins, listed in decreasing order of abundance, are galena, sphalerite, chalcopyrite, and pyrite. They generally comprise less than 1 per cent of the veins, although locally it is estimated that the galena and sphalerite content exceeds 5 per cent. The sulphide minerals generally occur as irregular masses and grains scattered at random from the walls to the center of the veins. Near the walls of one vein extremely thin bands of pyrite and brown sphalerite alternate with bands of fine fluorite, and the center of the vein is composed of coarsely crystalline fluorite. Sphalerite in almost all other veins, however, is a red or ruby blende variety. The galena contains a small quantity of silver in the form of microscopic argentite.

Quartz is the most abundant gangue mineral of the fluorite veins. It is commonly found in the vugs coating crystals of fluorite. Quartz in places forms pseudomorphs after rhombohedral calcite crystals and replaces the platy variety of calcite. An important occurrence of quartz in the veins is in the material known locally as "blastonite." This conchoidally fracturing material in thin section is seen to be composed of brecciated fluorite in a matrix of microcrystalline quartz (Fig. 4). The quartz cemented and partially replaced the brecciated fluorite. The quantity of fluorite in this material ranges from a few per cent to more than 80 per cent and is dependent upon the original content of fluorite in the breccia and upon the degree of replacement by silica. This material comprises more than 10 per cent of a few of the lower

grade veins. In one vein siliceous material swung from the hanging wall to the footwall with increasing depth. This cherty fluorite breccia generally bears horizontal striations and is believed to be chiefly of late hypogene origin, formed before the period of horizontal shearing came to a close.

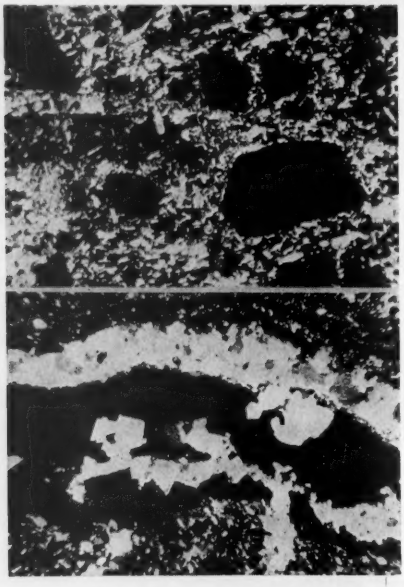

FIG. 4 (Upper). Breccia fragments of fluorite (dark) in a matrix of microcrystalline quartz. Thin section, crossed nicols. × 21.

FIG. 5 (Lower). Veinlet of fluorite (dark) and calcite (white) cutting coarsely crystalline fluorite with disseminated grains of calcite. Thin section, crossed nicols. × 21.

Calcite forms more than 10 per cent of a few of the lower grade veins. Calcite from some veins shows a pronounced platy structure, a form which is often found in epithermal veins. The calcite occurs in coarse bands parallel to the banded fluorite; in cockade structure interbanded with fluorite; as disseminated grains and

tiny veinlets in finely banded fluorite; with purple fluorite in breccia zones in the hanging wall and footwall; as scarce rhombohedral and scalenohedral crystals coating fluorite cubes; and in small irregular veinlets with fluorite cutting bands of coarsely crystalline fluorite (Fig. 5). In almost all of these types of occurrence the calcite is believed to be hypogene. Calcite from one of the veins fluoresces with a rose color.

Barite is not a very common gangue mineral. White or pale pink barite occurs as coarse crystals or platy masses intergrown with and coating fluorite crystals near the middle of some veins.

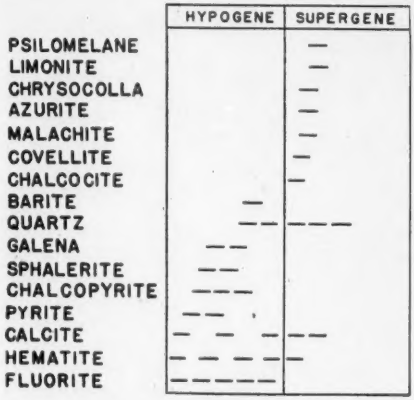

FIG. 6. Paragenesis of St. Lawrence fluorspar veins.

In one vein barite and fluorite locally form alternating bands about one-fourth inch thick.

Alteration products are present in very small quantities. Secondary minerals noted are limonite, hematite (in part), chalcocite, covellite, malachite, azurite, chrysocolla, and a psilomelane-like manganese mineral. These minerals occur as tiny veinlets cutting fluorite and sulphide minerals or as irregular masses and films coating fluorite crystals in vugs.

Paragenesis. The accompanying paragenesis chart (Fig. 6) is based upon studies of the veins in the field and laboratory studies

of thin sections and polished specimens. The minerals are arranged in the chart with the earliest minerals at the bottom. In almost all instances there was overlap of deposition between the adjacent minerals in the figure. Most minerals listed above barite are entirely secondary minerals. The emplacement of the hypogene minerals was a complex process involving many periods of brecciation and mineralization. The extended period of deposition of fluorite, hematite, and calcite is noteworthy.

FIG. 7. Complexly banded fluorspar with some breccia fragments of rhyolite porphyry and a few thin bands of sphalerite. Polished specimen. ×0.7.

Structures and Textures of Veins. The most striking structural feature of the fluorite veins is banding. The veins show several types of banding, but crustification in open spaces is apparently most common. Some layering is the result of reopening and refilling (Fig. 7). The symmetrical and asymmetrical banding parallel to the walls is formed chiefly by successive layers of fluorite of different color or texture. The thickness of a band

ranges from a fraction of an inch to more than 2 feet. In each lens of fluorite a definite order of color banding can usually be determined. This order, however, does not apply to the whole vein, for other lenses show distinctly different sequences of color. In several veins finely banded, fine-grained fluorite is near the walls (Fig. 9). This type of fluorspar is generally brick red or gray,

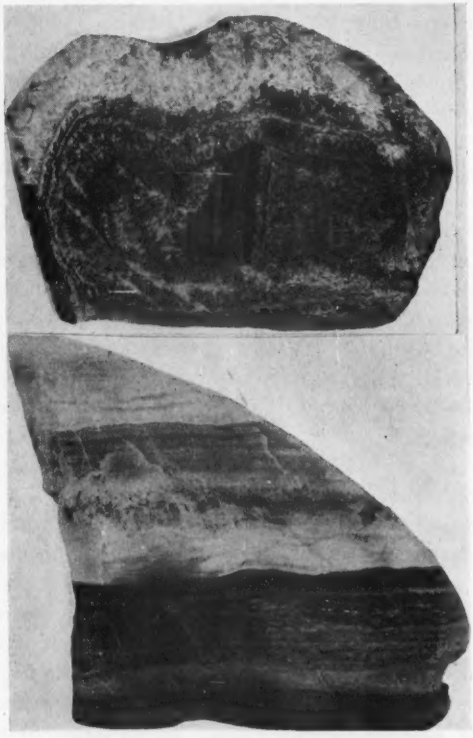

FIG. 8 (Upper). Nodule composed of bands of coarsely crystalline fluorite enveloping a nucleus of granite and fine-banded fluorite. Polished specimen. × 0.7.

FIG. 9 (Lower). Polished specimen of delicately banded, fine-grained, red and white fluorite. × 0.7.

but some is tan, purple, green, or white. Although some of this finely banded material contains grains of quartz or calcite, thin sections and analyses indicate that some contains more than 95 per cent of fluorite.

In addition to banding parallel to the walls, another type of banding is very common in the fluorite veins. This is found in nodules composed of fluorite layers of different color or texture around breccia fragments as nuclei. Bands of sulphide minerals locally accompany the fluorite. The banded fluorite is either coarsely crystalline or fine-grained, and the resultant material may be termed nodular, orbicular, or cockade. The breccia fragments at the center of the nodules are granite (Fig. 8), rhyolite porphyry, slate, coarse fluorite, and fine fluorite. The nodules nearer the walls of veins commonly have centers composed of the wall rock, and those nearer the center of veins commonly have nuclei of brecciated fluorite. The contacts of the angular breccia fragments and the banded fluorite are generally sharp, although a few fragments show a slight replacement of rhyolite porphyry and granite by fluorite. A few nodules about 4 inches in diameter were sectioned and found to contain a breccia fragment only an inch in diameter (Fig. 10), showing no evidence of replacement of the fragment by the subsequent bands of fluorite. Some loose nodules found on a stock pile are complete in the sense that the outer bands of fluorite are apparently not broken.

The origin of this nodular type of fluorspar is not simply one of cementation and partial replacement of fragments of fault breccia in contact with one another. The following hypothesis of origin is suggested. With repeated periods of movement and mineralization throughout the history of the veins, it is possible that the nodular fluorspar formed by the alternate deposition of fluorite and rotation of the growing nodule between the walls of the vein or adjacent nodules. Thus, earlier points of support of the nodules would also be covered by subsequent bands of fluorite, and structures suggesting unsupported inclusions would result. Local truncation of fluorite bands by later bands generally at small angles may be considered as support of this rotation hypothesis (Fig. 11). The eccentric growth and uneven coating of succes-

sive minerals are considered to be criteria of the directional flow of mineralizing solutions (35, 1). The thicker parts of successive bands of fluorite here are not commonly on the same side of the nucleus of a nodule but are on different sides. If the source of the mineralizing solutions in a vein is considered to be constant, rotation of the nodule is again suggested.

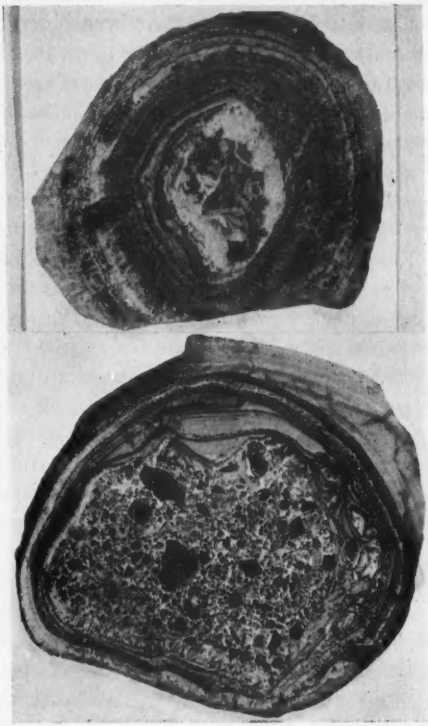

FIG. 10 (Upper). Nodule composed of bands of fluorite and calcite enveloping a nucleus of fluorite (dark) and calcite (white). Polished specimen. × 0.6.

FIG. 11. (Lower). Nodule composed of fine-banded fluorite enveloping a nucleus of brecciated hornfels cemented by calcite. Polished specimen. × 0.3.

Another prominent structural characteristic is the vuggy nature of the veins. In plan some vugs measure 3 feet by 20 feet and are elongated parallel to the length of the vein. The greatest dimension, however, is commonly vertical, some vugs extending for a vertical distance of more than 100 feet. In a few vugs considerable quantities of clay were encountered in mining operations. The vugs are lined generally with cubes of fluorite, although octahedral and even botryoidal fluorite have been observed. Quartz, calcite, and small quantities of secondary minerals of copper and iron locally coat the fluorite crystals. In several veins quartz crystals occur in the vugs as overgrowths chiefly on the upper sides of fluorite crystals, and the direction of elongation of the crystals is dominantly upward. Similarly, surface coatings of limonite and hematite are commonly on the upper sides of fluorite crystals in the vugs.

Zoning. Regional zoning is shown in the St. Lawrence district by the distribution of barite and green fluorite. Barite is rare or lacking in most veins, but it is more conspicuous in veins in the southwestern part of the granite area. Fluorite from veins beyond the western contact of the St. Lawrence granite and slate is generally green, octahedral rather than cubic, and strongly fluorescent. The green color prevails regardless of whether the vein cuts rhyolite porphyry, slate, or hornfels. In veins in the granite, as the eastern or western granite contact is approached along the strike of the veins, the quantity of green fluorite increases.

Classification. The fluorspar veins at St. Lawrence are classified as epithermal on a basis of the low temperature and pressure mineral assemblage, the vuggy nature of the veins, and the abundance of breccia, fine banding, and crustification structure. The presence of cherty silica, platy calcite, and barite are especially indicative of the epithermal class.

Origin. The source of the fluorite is believed to have been the same magma reservoir that supplied material to form the granite and associated bodies of rhyolite porphyry and lamprophyre. The close spatial relation of the fluorite veins and these

rocks is considered to be genetic and not merely structural control of the mineralizing solutions. Fluorite is abundant as an accessory mineral of the granite and is common in the miarolitic cavities.

The relation of the fluorite veins and lamprophyre dikes is clearly shown at three places. In one instance a dike was strike-faulted and mineralized with fluorite. The contact of granite and another lamprophyre dike is extensively mineralized with fluorite. At a third place fluorite emanations were ponded or channelized in a fissure on one side of a dike, and apparently only slight mineralization occurred on the other side.

The vein-forming processes that operated at St. Lawrence are chiefly fissure filling and accretion, replacement apparently being of small importance. Accretion involves the alternate brecciation of previously deposited vein matter, followed by recementation and filling of the open spaces (20). With decrease in the periods of movement along the fissures, the deposition of fluorite slackened. It is a fact that no conclusive post-fluorite faults have been found displacing the veins other than a few small faults along the flat sheeting structure of the granite.

No field evidence was found to show that any of the fluorite is supergene. Silver-bearing galena, often considered an indication of the magmatic origin of ore-forming solutions, occurs even in the middle of some fluorite veins. A chemical analysis of water from the 150-foot level of one of the mines shows a fluoride content of only 1.6 parts per million. The analysis was made for the Geological Survey of Newfoundland by Dr. G. A. Abbot, University of North Dakota. It is concluded that supergene fluorite is not commercially important, if present at all, at St. Lawrence.

Grade of Fluorspar and Reserves. The grade of the two types of fluorspar at St. Lawrence may be summarized as follows:

	CaF_2 %	SiO_2 %	$CaCO_3$ %	Fe_2O_3 and Al_2O_3 %
High grade	94–98	1– 4	0.5– 1	0.5–1.5
Lower grade	70–80	10–15	7 –10	3 –5

No marked changes in the mineralogy or grade of the fluorspar veins have been observed with increased depth of mining to a level of 350 feet. Vertical zoning may never be detected at St. Lawrence, where most veins occupy fissures in a granite whose physical and chemical character is not expected to change within the depth of mining. It is possible, however, that the sulphide content of the veins may increase in depth and fewer vugs and breccia may be encountered in the fluorspar.

Epithermal veins like these fluorspar veins are believed to form at temperatures ranging from 50° C. to 200° C., and from the surface to a depth of as much as 6,000 feet. At St. Lawrence the veins apparently have been only slightly eroded since their formation near the roof of the miarolitic granite intrusive.

Because the fluorspar veins occupy fault fissures and not joints, they may be expected to have a greater vertical range. Some of these mineralized fault fissures have been traced along the strike for more than a mile. A conservative estimate of the depth of a vein is one-half of the length. Since the ends of no fluorspar veins at St. Lawrence have actually been observed, it is reasonable to expect these veins to continue to a depth greater than 1,000 feet. Whether the fluorspar veins are of mineable width and grade at such a depth only future mining or drilling can prove.

In view of the lack of systematic development work in advance of mining on most veins, any estimate of fluorspar reserves at St. Lawrence must be based largely on geologic inferences. It is not unreasonable, however, to expect the St. Lawrence district to produce several million tons of fluorspar and to become one of the chief sources of the world's supply.

Mining and Milling. The St. Lawrence Corporation of Newfoundland, Ltd. and Newfoundland Fluorspar Limited are mining fluorspar at St. Lawrence. All mining is done underground by a form of shrinkage stoping. The walls of the veins require almost no timber for support. Shafts have been sunk and underground work has been done on 7 veins, but nearly all of the present production is from 4 veins. Mining has progressed to a maximum

depth of 350 feet, and no vein has been mined to the lower limit of workable fluorspar. Drainage may be the dominant factor in determining the practicable depth of mining at St. Lawrence. The mines are very wet because of the numerous vugs in the veins, the pronounced joints, sheeting structures, and faults in the granite, and the location in an area of high annual precipitation.

Treatment of the fluorspar originally consisted of washing, handpicking, and crushing. Later a more elaborate mill with jigs and tables was employed by the St. Lawrence Corporation of Newfoundland, Ltd. This company has recently installed a flotation plant at St. Lawrence. Newfoundland Fluorspar Limited ships crushed fluorspar to Arvida, Quebec, where it is also treated by flotation. Sulphide minerals from the jig and table concentrates were often saved when pockets were met in mining operations. It is possible that with the recent use of flotation the St. Lawrence district will have a small lead and zinc production.

Shipments. Newfoundland has shipped fluorspar since 1933 and all production has come from the St. Lawrence district. Shipments have increased almost steadily, and the total shipments from 1933 through 1941 amounted to about 79,000 short tons (9, 10). About half of this tonnage contained better than 93 per cent of CaF_2 and the remainder contained 85 to 93 per cent. About one-fourth of the fluorspar came to the United States and three-fourths went to Canada for use in the steel, aluminum, cyanamid, and hydrofluoric acid industries. All of these shipments were made by the St. Lawrence Corporation of Newfoundland, Ltd. It is expected that shipments of fluorspar will be greatly increased both by this company and by Newfoundland Fluorspar Limited, a subsidiary of the Aluminum Company of Canada, Ltd.

Comparison with other Fluorspar Deposits. Commercial deposits of fluorspar in felsic granitoid rocks are found throughout the world. In the United States fluorspar deposits occur in granite or closely related rocks in the following localities: Deming, New Mexico (8, 21); Jamestown, Colorado (15); Northgate, Colorado (4, p. 379); Keller, Washington (4, p. 389); and Westmoreland, New Hampshire, (2). The following foreign fluor-

spar deposits are in part or entirely in granite: Madoc, Ontario (40, 14); Grand Forks, British Columbia (41, p. 27); San Luis Potosi, Mexico (24, p. 152); Cordoba, Argentina (30); Central Massif of France (5); Saxony and Bavaria, Germany (17, p. 340; 32); Tadjikistan, U. S. S. R. (29, p. 159, 166); and Carboona, N. S. Wales, Australia (31).

Most commercial fluorspar deposits of the world are classed as epithermal or telethermal, and a few represent the mesothermal class. An unusual occurrence of commercial fluorspar in a pegmatite in the Bushveld granite of South Africa has been recorded (36).

In common with the St. Lawrence fluorspar district, fluorite is associated with microcrystalline quartz, chalcedony, or chert in several other deposits. This association is typical of the fluorspar deposits of western United States (4, p. 388). Late chalcedony and opal are found in vugs in the quartz-fluorite veins with gold tellurides at Cripple Creek, Colorado (27). Near Sweetwater, Tennessee, are veins containing an intimate mixture of fluorite, calcite, barite, and chert (24, p. 142; 26). At Grand Forks, British Columbia, late chert contains inclusions of fluorite and barite (41, p. 27). Miller and Singewald (30) report the presence of chalcedony with inclusions of microscopic fluorite in the fluorspar veins at Cordoba, Argentina. Chalcedony and chert are found in the late-Carboniferous fluorspar veins of the Pennine districts of England (13, p. 472). Late chert occurs in fluorspar veins in the Central Massif of France (25, 6) and in U. S. S. R. at Kalangui and Solonechnoie, Eastern Transbaikalia (29, pp. 81, 96).

Studies of several districts where fluorspar occurs along faults which displace sedimentary beds show that the fluorspar veins, as at St. Lawrence, were formed along normal faults or horizontal shears. In the Illinois-Kentucky district Bastin (3, p. 67) reports that the mineralized fault fissures are normal faults. Currier (7, p. 252) notes that horizontal striations on the walls here are locally superimposed on vertical striations. The Rosiclare fault has been traced for more than four and a half miles and it has been pro-

ductive of fluorspar for a length of about three miles (16). As in the St. Lawrence district, the fluorspar veins in the Illinois-Kentucky district are later than lamprophyre dikes (7, pp. 238, 241). In England in the Derbyshire district (37, 38) and in the Durham, Cumberland, and Weardale districts (12, pp. 693, 718) the fluorspar veins occupy normal and strike-slip faults. At Madoc, Ontario, the mineralized fault fissures are horizontal shears (14).

Cockade structure, similar to that found at St. Lawrence, has also been described in fluorspar veins in New Mexico (21, p. 71) and at Northgate, Colorado (4, p. 379). In U. S. S. R. cockade structure is found in fluorspar veins at Kalangui, Eastern Transbaikalia (29, pp. 71–74) and at Takob, Tadjikistan (29, pp. 166, 167).

As at St. Lawrence, purple fluorite is early and is especially common near the margins of veins in several other deposits. At Deming, New Mexico (8, p. 540), Madoc, Ontario (14), and Puy-de-Dôme, France (6) early purple fluorite is found next to the walls of the veins. At Cripple Creek, Colorado, purple fluorite is older than the lighter colored fluorite and gold tellurides (28). In the North Pennine district of England, purple and green fluorite is believed to have formed at a higher temperature than the yellow variety found with barite in the outer zones of the district (12, p. 694). In a general review of fluorite occurrences in Canada, Wilson (41, p. 2) suggests that purple or deep violet fluorite formed at higher temperatures than fluorite of other colors.

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Thanks are due to Dr. E. C. Harder and Dr. W. S. Smith of Newfoundland Fluorspar Limited and to Mr. W. E. Seibert and Mr. D. A. Poynter of the St. Lawrence Corporation of Newfoundland, Ltd., for full coöperation and the use of company facilities.

The writer also wishes to express his thanks to the Geological Survey of Newfoundland for an analysis of mine water and some thin sections. The Geology Department of Princeton University made available the use of its laboratories, contributed rock analyses and some thin sections, and financed part of the photographic work.

U. S. Geological Survey, Alaskan Branch,
Washington, D. C.
May 28, 1943.

BIBLIOGRAPHY.

1. Bandy, M. C.: Direction of flow of mineralizing solutions, (disc.). Econ. Geol., 37: 330–333, 1942.
2. Bannerman, H. M.: The fluorite deposits of Cheshire County, New Hampshire. New Hampshire Min. Res. Surv., Part 5, 1941.
3. Bastin, E. S.: The fluorspar deposits of Hardin and Pope Counties, Illinois. Illinois Geol. Surv., Bull. 58, 1931.
4. Burchard, E. F.: Fluorspar deposits in western United States. A. I. M. E., Trans. 109: 370–396, 1934.
5. Chermette, M. A., and Sire, M.: Le spath-fluor dans le Massif Central. Mines, Carrières, 99: 25–28, 1931.
6. ——: Le spath-fluor dans le Massif Central. Mines, Carrières, 101: 21–28, 1931.
7. Currier, L. W.: Geology of Hardin County, Illinois. Illinois Geol. Surv., Bull. 41, 1920.
8. Darton, N. H., and Burchard, E. F.: Fluorspar near Deming, New Mexico. U. S. Geol. Surv. Bull. 470: 533–545, 1910.
9. Davis, H. W.: Fluorspar and cryolite. U. S. Bur. Mines, Min. Yearbook, 1937, 1938.
10. Davis, H. W., and Trought, M. E.: Fluorspar and cryolite. U. S. Bur. Mines, Min. Yearbook, 1939, 1940, 1941.
11. Drugman, Julien: Different habits of fluorite crystals. Min. Mag., 23: 137–144, 1932.
12. Dunham, K. C.: The genesis of the North Pennine ore deposits. Geol. Soc. London Quar. Jour., 90: 689–720, 1934.
13. Dunham, K. C.: The paragenesis and color of fluorite in the English Pennines. Am. Min., 22: 468–478, 1937.

14. Emery, C. L.: Fluorspar ores of Madoc, Ontario. Canadian Min. Jour., 61: 667–668, 1940.
15. Goddard, E. N.: The influence of Tertiary intrusive structural features on mineral deposits at Jamestown, Colorado. Econ. Geol., 30: 370–386, 1935.
16. Hatmaker, Paul, and Davis, H. W.: The fluorspar industry of the United States with special reference to the Illinois-Kentucky district. Illinois Geol. Surv., Bull. 59, 1938.
17. Hoenes, D.: Gesteine und Erzlagerstätten im Schwarzwälder Grundgebirge. Neues Jahrb., Beil.-Bd. 72, Abt. A: 265–346, 1937.
18. Howse, C. K.: St. Lawrence fluorspar mines, in Snelgrove, A. K.: Mines and mineral resources in Newfoundland. Newfoundland Geol. Surv. Inf. Circ. No. 4: 26–32, 1938.
19. Howse, C. K., and Fischer, R. P.: Newfoundland ships fluorspar. Eng. and Min. Jour., 140: 42–45, 1939.
20. Hulin, C. D.: Structural control of ore deposition. Econ. Geol., 24: 15–49, 1929.
21. Johnston, W. D.: Fluorspar in New Mexico. New Mexico Bur. Mines, Bull. 4, 1928.
22. Jukes, J. B.: General report of the Geol. Surv. of Newfoundland for 1839 and 1840: 83–87, 133, 154, London, 1843.
23. Kalb, George, and Koch, Leo: Die Kristalltracht des Flusspates und Bleiglanzes in minerogenetischer Betrachtung. Centr. für Miner. etc., Abt. A: 308–313, 1929.
24. Ladoo, R. B.: Fluorspar- its mining, milling, and utilization. U. S. Bur. Mines, Bull. 244: 1–180, 1927.
25. Lance, R. D.: Le spath-fluor; repartition géographique des venues fluorées en France. Mines, Carrières, 85: 121–123, 1929.
26. Laurence, R. A.: Origin of the Sweetwater, Tenn., barite deposits. Econ. Geol., 34: 190–200, 1939.
27. Lindgren, Waldemar, and Ransome, F. L.: Geology and gold deposits of the Cripple Creek district, Colo. U. S. Geol. Surv. Prof. Pap. 54, 1906.
28. Loughlin, G. F., and Koschmann, A. H.: Geology and ore deposits of the Cripple Creek district, Colorado. Colo. Sci. Soc. Proc., 13, No. 6; 294, 295, 1935.
29. Luchitsky, V. I.: Fluorspar in U. S. S. R. Trans. All-Union Sci. Res. Inst. of Econ. Miner., 119: 330 pp. with 2 page summary in English, 1937.
30. Miller, B. L., and Singewald, J. T.: Mineral Deposits of South America. McGraw-Hill, 1919. P. 54.
31. Min. Trade Notes: Fluorspar. U. S. Bur. Mines, 2, No. 2: 30, 1936.
32. ——: Fluorspar. U. S. Bur. Mines, 3, No. 3: 24–25, 1936.
33. Murray, Alexander, and Howley, J. P.: Geol. Surv. of Newfoundland reports for 1864–1880: 99, 105–106, 232–236, London, 1881.
34. ——: Geol. Surv. of Newfoundland reports for 1881–1909: 222–223, 227–228, 232, 250, 451, St. John's, Nfld., 1918.
35. Newhouse, W. H.: The direction of flow of mineralizing solutions. Econ. Geol., 36: 612–629, 1941.
36. Sinclair, W. E.: Fluorspar in South Africa. Min. Mag. 55: 265–270, 1936.

37. Traill, J. G.: The geology and development of Mill Close Mine, Derbyshire. Econ. Geol., 34: 851–889, 1939.

38. Wedd, C. B., and Drabble, G. C.: The fluorspar deposits of Derbyshire. Inst. Min. Eng. Trans., 35: 501–534, 1907–1908.

39. White, D. E.: The molybdenite deposits of the Rencontre East area, Newfoundland. Econ. Geol., 35: 967–995, 1940.

40. Wilson, M. E.: Fluorspar deposits of the Madoc district, Ontario. Canada Geol. Surv., Summ. Rept. 1920, part D: 41–78, 1921.

41. ——: Fluorspar deposits of Canada. Canada Geol. Surv., Econ. Geol. Ser., No. 6, 1929.

SOME PORPHYRY–SEDIMENT CONTACTS AT THE DOME MINE, ONTARIO.

TERENCE C. HOLMES.

ABSTRACT.

Both porphyry and Temiskaming sediments occur in considerable volume in the Dome mine. At several places rocks are found along their contacts which have the general appearance of porphyry except for numerous, more or less faint outlines which resemble the pebbles in the Temiskaming conglomerate. It is the writer's opinion that these faint outlines represent pebbles in a conglomerate which has been altered by solutions emanating from a magma to a rock which resembles in some degree the porphyry bodies of the mine. The degree to which it resembles the porphyry depends on the extent of the alteration process.

THE Dome mine lies in the Porcupine gold mining area of Ontario. It is the only mine in the camp in which both porphyry and Temiskaming sediments occur. Contacts between these two formations are exposed at a number of places in the workings and display some interesting and unusual features which are described below. An hypothesis for the genesis of these features is offered at the end of the paper.

SEDIMENTS.

The sedimentary series in the mine is made up of a considerable number of interbedded or interfingering slate and conglomerate members. Except for an occasional thick greywacke bed in the slate, no other rock types are found in this series in the mine. They have been mapped [1] as belonging to the Temiskaming series; that is, to the younger of the two sedimentary series in the area.

The typical slate is a well-bedded dark rock. Individual beds usually consist of a coarse- and a fine-grained portion, many with a well-marked gradation between them. In some places the

[1] Hurst, M. E.: Porcupine Area, Map No. 47A. Ontario Dept. of Mines, Third Edit., 1939.

coarse portions are lacking from the beds, in which case the bedding is much less prominent. The thickness is usually between one-sixteenth and one-half inch. Attention is drawn to the marked tendency which exists for all the beds in any small area to be of nearly the same thickness and composition.

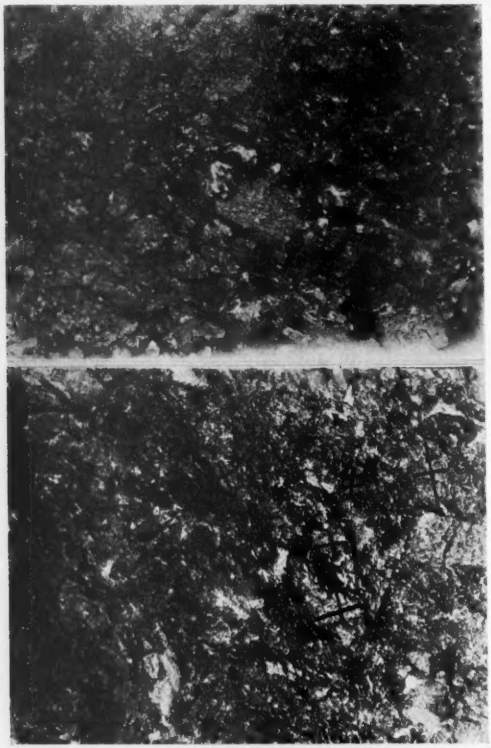

FIG. 1 (Upper). Normal conglomerate. The area shown is about 36 inches long.

FIG. 2 (Lower). Shadow pebbles about five feet from normal slate. A number of the pebbles are marked with a cross with arms extending to the edges of the pebbles. The area shown is about 14 inches long. The very bright irregular spots are scars on the rock from blasting.

The conglomerate (Fig. 1) consists of thickset pebbles in a sparse matrix. The pebbles are of assorted sizes, smaller ones filling in most of the space between the larger ones. In a general way the pebbles are rounded but in detail the outlines are irregular. It is thought that this irregularity is due to the very considerable deformation which the rock has undergone, rather than to the original shape. In general the pebbles are now several times longer than they originally were.[2] Over half the pebbles are derived from acid intrusives and most of these, judging from their texture, are from plutonic rather than hypabyssal rocks. The remaining pebbles are chiefly from volcanic rocks and show a wide range of composition. Pebbles which resemble the highly altered rocks comprising the great bulk of the porphyry in the mine occur only sparingly. With the exception of these practically all the pebbles appear to have been derived from fresh rocks and still very largely retain their fresh appearance, contrasting strikingly with the porphyry.

PORPHYRY.

The porphyry bodies to which this paper has particular reference are roughly lenticular in plan and their length is measured in hundreds of feet. The rocks in them show considerable variety, and the great majority have a highly altered appearance. Most are light grey, buff or cream colored with dark gray phases locally. The great bulk of the rock is too fine grained to allow its constituent minerals to be positively identified in hand specimens, but sericite, acid feldspar and carbonate are probably important; some appears to be highly carbonated. Schistosity is found almost everywhere, but is less prominent in some phases, particularly in those which are highly carbonated. It is not known whether this is because the alteration has obscured an earlier schistosity or because the effects of the schisting are less prominent in certain phases of the rock. That is, the relative age of the alteration and the schisting are uncertain. In about half of the porphyry, euhedral quartz crystals, large enough to be readily identified, can be

[2] This was pointed out to me by Mr. E. L. Evans.

found and amount to as much as five per cent, rather evenly distributed through the rock. They would ordinarily be regarded as phenocrysts but the presence of similar crystals here and there in the sediments, similarly distributed and clearly secondary, suggests that they may be metacrysts.

At a few places numerous feldspar crystals are found, sharply outlined and standing out from the matrix with varying degrees of distinctness. Where best developed this phase of the porphyry has a black, dense matrix and resembles many a feldspar porphyry dike rock. However, this occurs along contacts with the "Carbonate Rock," a rock so altered that no hint of its original character remains, and suggests the possibility that the feldspar crystals are metacrysts and not phenocrysts and that this phase of the porphyry may actually be not the freshest, as its appearance indicates, but the most highly altered.

Most geologists who have worked in the Porcupine camp, including many who have never published their conclusions, seem to believe that the porphyry was later than the Temiskaming sediments.[3] Gratton, McKinstry, and others thought the porphyry was probably pre-Temiskaming[4] but were not certain. M. E. Hurst also favored this at one time[5] but later appears to have concluded that most, if not all of the porphyry, is post-Temiskaming.[6]

[3] Robinson, H. S.: Geology of the Pearl Lake area, Porcupine District, Ontario. Econ. Geol. 18: 757, 1923.

Burrows, A. G.: The Porcupine gold area. Ont. Dept. Mines, Ann. Rept. Vol. 33, Pt. 2, 1924; Disc. of "Outstanding features of Hollinger geology." Canadian Inst. Min. Met. Trans. 36: 606–7, 1933.

Whitman, A. R.: Disc. of "Outstanding features of Hollinger geology." Canadian Inst. Min. Met. Trans. 36: 607–8, 1933. This is believed to be the latest published expression of Dr. Whitman's views.

Langford, G. B.: Geology of the McIntyre mine. A. I. M. E. Tech. Pub. 903, 1938.

[4] Outstanding features of Hollinger geology. Canadian Inst. Min. Met. Trans. 36: 6–7, 15–16, 1933.

[5] Recent studies in the Porcupine area. Canadian Inst. Min. Met. Trans. 39: 450–451, 1936.

[6] Porcupine Area, Map No. 47A. Ont. Dept. of Mines, Third Edit., 1939.

PORPHYRY-SEDIMENT CONTACTS.

Porphyry-sediment contacts are seen at a number of places in the mine workings. In several cases there is a zone between undoubted sediment and undoubted porphyry in which more or less distinct outlines can be seen that resemble the larger pebbles in the conglomerate (Figs. 2 and 3). As a rule these shadow pebbles occur in small areas, separated by normal sericite schist or porphyry in which no suggestion of pebbles can be found. In general the shadow pebbles are more distinct and the areas in which they are found make up a greater proportion of the rock as the sediments are approached, but reversals of this trend for short distances are common. They do not usually extend more than twenty-five feet from the undoubted sediments. The size and spacing of the shadow pebbles would resemble the pattern of the conglomerate if the small interstitial pebbles and a few of the larger pebbles were removed from it. The outlines of many of the shadow pebbles are rather vague but on the whole they appear to be somewhat more irregular than the pebbles in the conglomerate. The rock which composes them is much altered, resembling in varying degree that in the adjacent porphyry and contrasting with the fresh rocks which make most of the pebbles in the conglomerate.

In all but one place where shadow pebbles were observed the nearest undoubted sediment is slate. In only one place is it conglomerate. If the undoubted sediment is slate there is a sharp contact between it and the zone in which shadow pebbles occur. The bedding near the contact may be somewhat obscured but there is no room for doubt as to the identity of the rock. The distinctness of the shadow pebbles and the width of the zone in which they occur is variable. The place in which the undoubted sediment is conglomerate was one of the first examined in the mine and as the problem discussed in this paper had not been raised at that time, it did not receive all the attention it might have. The part of the mine in which it lies is no longer accessible for further study. The impression gained at the time was that the porphyry graded into conglomerate in about fifteen feet.

If no shadow pebbles are found, the contact between the slate and the porphyry is usually knife sharp. In one place however, several thin sills of porphyry lie in the slate near the contact. On approaching the contact from one of the sills, the first feature

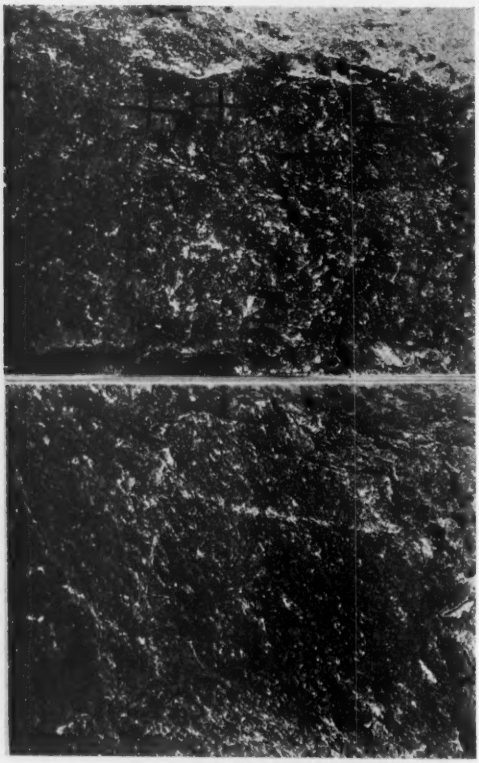

FIG. 3 (Upper). Shadow pebbles about 15 feet from normal slate. A number of the pebbles are marked as in Figure 2. They stand out less prominently from the matrix than those in Figure 2. The area shown is about 14 inches long.

FIG. 4 (Lower). Normal porphyry. The area shown is about 36 inches long.

noted is very thin layers of dense buff material traversing the sill. The layers are parallel to the beds in the slate and each one together with the intervening porphyry is equal in thickness to one bed of the adjacent slate. They pass into slate beds along the strike. Crossing the strike toward the slate they become progressively thicker, darker and more argillaceous and the intervening material becomes narrower. When the layers are definitely argillaceous in appearance the texture of the intervening material begins to grade from that of the porphyry to that of the graywacke phases of the ordinary slate and completes the gradation a few beds farther. The whole gradation occurs in the space of a few inches.

At a few places narrow bands of slate have been found a short distance out in the porphyry from the sediments. The rock is lighter in color than the normal slate and the bedding is obscured or obliterated. The strike and dip of the bands are parallel to those in the adjacent sediments. Shadow pebbles can usually be found in the porphyry between these bands and the main body of the sediments.

HYPOTHESIS.

In order to account for the features described above, an hypothesis has been gradually built up. It is thought that the sediments have been altered to a rock resembling porphyry by magmatic emanations. Judging by the appearance of the various rocks, the difference in chemical composition between the conglomerate and porphyry is much less than that between the porphyry and the slate, especially the argillaceous parts. This would make it easier for the conglomerate to be altered to porphyry. Also, and probably more important, the permeability of the conglomerate is thought to have been relatively high compared to that of the slate, so that the emanations traversed it freely and alteration could proceed in it over quite a wide zone at one time. It is thought that the permeability was quite variable locally, resulting in the more permeable parts being completely altered while islands of somewhat less permeable material remain only partly altered

and showing shadow pebbles. The matrix and the smaller pebbles appear to have been completely altered well before the larger pebbles.

The slate is thought to have been substantially less permeable and not easily replaceable. Emanations which entered it probably spread much more freely along the graywacke portions of the beds than through the argillaceous portions. This is considered to account for the widespread parallelism of the porphyry-slate contacts with the bedding.

If it is true that at least part of the porphyry along the contact was formed by alteration, the next question is how much of it was formed in this manner and how much, if any, was formed by freezing of a magma. It is believed that all the material lying between undoubted sediments and the shadow pebbles most remote from them was formed by replacement. Beyond this zone only less direct, and hence weaker, lines of reasoning are available. The similarity of the porphyry beyond the zones of shadow pebble areas to the porphyry between those areas suggests a similar genesis. The writer has seen no porphyry in the mine, except that described from near the "Carbonate Rock," sufficiently different from that within the shadow pebble zones to suggest that its genesis is radically different. However it must be pointed out that all of the rocks under consideration have been intensely sheared and altered and this may have obscured the differences. Against this stands the fact that the pebbles in the conglomerate, although they have been strongly deformed, are fresh looking and display granitic and other primary textures whereas the porphyry is schistose and highly altered. It would seem likely that if the porphyry had the texture typical of such rocks when fresh it would retain that texture as well as the pebbles of more or less similar composition in the adjacent conglomerate which were so strongly deformed by the shearing.

It is presumed that the agents which caused the alteration emanated from a magma, but whether it was at the elevation at which the observations were made or deeper, possibly far below the present mine workings, is uncertain. If all the porphyry at

the elevation of the workings was formed by replacement the magma must have been deeper.

To summarize the writer's conclusions as to the genesis of the porphyry seen in the mine: The evidence that the parts of the porphyry in and among the shadow pebble areas have been formed by replacement of sediments is strong. Evidence bearing on the genesis of the parts beyond the shadow pebble areas is both weak and meagre. However, there is enough indication of formation by replacement that this possibility must be borne in mind.

CONTEMPORARY INVESTIGATION.

At about the time that the relations described above first attracted the writer's attention Mr. E. L. Evans commenced a study of the porphyries in the Porcupine camp. It was some time after this before Mr. Evans and the writer met and by that time both had formed their main conclusions. These were substantially the same. Mr. Evans' work is the basis of a thesis entitled "The Porphyry of the Porcupine District" which was submitted to Columbia University and a paper to be published shortly by the Geological Society of America.

SOUTH PORCUPINE, ONTARIO,
June 4, 1943.

THE DIFFERENTIATION OF MAGNESITE FROM DOLOMITE IN CONCENTRATES AND TAILINGS.[1]

GEORGE T. FAUST.

ABSTRACT.

A new method is presented here for differentiating magnesite from dolomite in crushed materials. This method is based on the essentially different temperatures at which these minerals undergo thermal decomposition. The resulting lowly birefringent periclase is easily distinguished microscopically from the highly birefringent dolomite. This method is based on the ease of recognition of the periclase which permits rapid counting and gives reliable quantitative data on mineral composition. A method is given for staining thermally treated specimens for the determination of the distribution of these minerals in rock fragments.

INTRODUCTION.

Salt brines,[2] in the past, have been the chief source of metallic magnesium in this country. The current demand for this metal has caused industry to seek additional raw materials. Accordingly, producers in large part have turned directly to magnesian minerals. Magnesite ($MgCO_3$), brucite ($Mg[OH]_2$), and dolomite ($CaCO_3.MgCO_3$) have now assumed importance as industrial sources for this metal. These minerals[3] are commonly found in deposits in which magnesite is the mineral of commercial importance. The mutual occurrence of magnesite and dolomite presents a real difficulty in the mineralogical analysis of the products of milling.

[1] Published by permission of the Director of the Geological Survey, United States Department of the Interior.

[2] Gann, J. A.: The magnesium industry. Jour. Ind. Eng. Chem. 22: 694–700, 1930.

[3] Callaghan, E.: Brucite deposit, Paradise Range, Nevada. Nevada Bur. Mines Bull. 27: 1–34, 1933. Hewett, D. F., Callaghan, E., Moore, B. N., Nolan, T. B., Rubey, W. W., and Schaller, W. T.: Mineral resources of the region around Boulder Dam. U. S. Geol. Surv., Bull. 871: 113–144, 1936.

The problem of developing a method for distinguishing magnesite from dolomite was suggested in connection with the program on strategic minerals. The method reported in this paper, developed in the petrologic laboratory of the Geological survey, has been found suitable for evaluating the magnesite content of ground materials. It has the advantage that no unusual equipment is required and differentiation is satisfactory.

THERMAL DISSOCIATION DATA.

The chemical and physical properties of dolomite and magnesite are so similar that preferential staining methods appeared to offer a less promising method of differentiation than the temperatures at which these minerals undergo thermal dissociation. The three carbonates (calcite, dolomite, and magnesite) when calcined give up their carbon dioxide and dissociate into their respective oxides at distinctly different temperatures. The curves representing their thermal decomposition are given in Figure 1. These thermal curves were made by Dr. L. T. Alexander [4] of the Bureau of Plant Industry, U. S. Department of Agriculture, according to the methods of Le Chatelier [5] as modified by Norton [6] and by Hendricks and Alexander.[7] The rate of heating was about 12° C. per minute. The diagonal line in the diagrams is a graph of the furnace temperature as a function of the time.

As shown in Figure 1, calcite and magnesite decompose in a single stage to lime (CaO) and periclase (MgO) respectively, whereas dolomite decomposes first into an intimate mixture of periclase and calcite and subsequently the calcite undergoes dissociation. The temperatures at which the dolomite breaks down into periclase and calcite is about 130° C. above that at which magnesite decomposes *at this particular rate of heating.* As this

[4] These data are taken from some unpublished results by Alexander and Faust.

[5] Le Chatelier, H.: De L'Action de la Chaleur sur les Argiles. Bull. Soc. Min. 10: 204–211, 1887.

[6] Norton, F. H.: Critical study of the differential thermal method for the identification of the clay minerals. Amer. Ceramic Soc. Jour. 22: 54–63, 1939.

[7] Hendricks, S. B. and Alexander, L. T.: Minerals present in soil colloids. I. Description and methods for identification. Soil Sci. 48: 257–268, 1939.

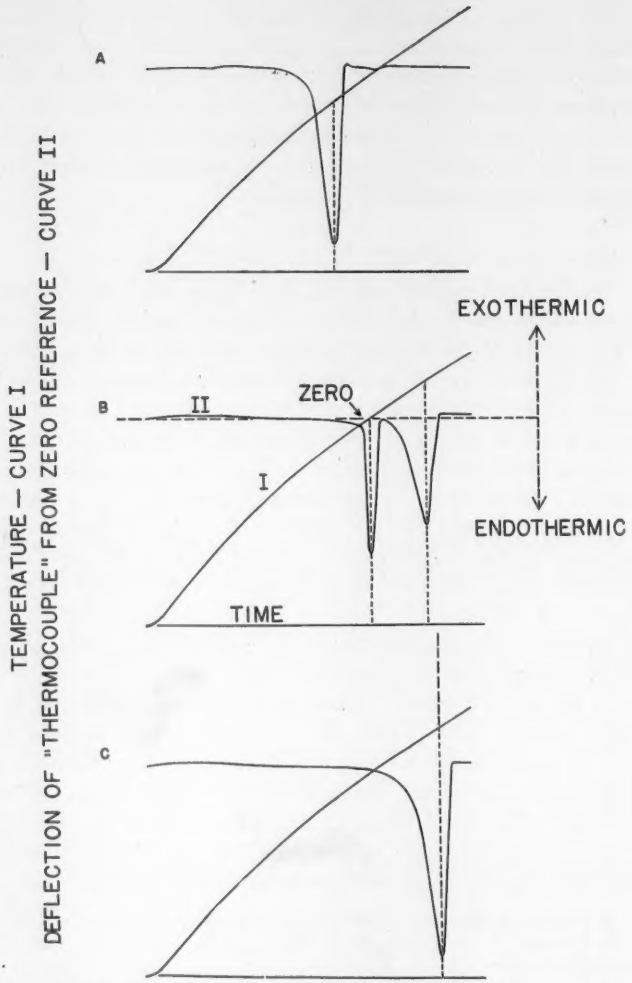

FIG. 1. Differential heating curves for some of the rhombohedral carbonates. Photographic records. (A) Magnesite (dense porcelainous type) Maltby Mine, Livermore, California. (B) Dolomite, Millville, West Virginia. (C) Calcite, Highway cut, one-half mile N.E. of Myersville, Maryland.

method of thermal analysis gives results that are apparently dependent upon the heating rate these temperatures *may consequently vary somewhat from equilibrium values.* It is also apparent that the decomposition of the calcite in the intimate mixture with periclase takes place at a temperature below that at which pure calcite dissociates. This difference is probably due to the fine particle-size of the calcite originating from the decomposition of the dolomite. Particle size influences the character of the thermal curves in such irreversible processes.

Thermal studies on carbonates by another method known as the "static method" have been made by many investigators. The work of A. F. Gill [8] in Canada has been an outstanding aid in the application of differential calcination processes to industrial separations.

THE EXPERIMENTAL PROCEDURE.

The method under consideration consists of selectively calcining the magnesite in a magnesite-dolomite mixture at a temperature that leaves the dolomite unaffected. The resulting mixture then consists of two substances (unaltered dolomite, ($MgCO_3.CaCO_3$) and periclase, (MgO)) which differ widely in their optical properties, birefringence being the most easily observed. The periclase exhibits anomalous, low, gray interference colors; the dolomite exhibits whites of a very high order. This great difference in birefringence permits the counting of the particles under the microscope with relative ease and rapidity (Fig. 2).

Samples used in this study, from the occurrence at Luning, Nevada (Callaghan [9]), were furnished by Basic Magnesium Incorporated.

Preparation of the Sample. To facilitate counting the grains, it is desirable to size the sample. The material studied was split into two fractions—a plus 200 mesh and a minus 200 mesh fraction. The minus 200 mesh fraction was then stirred in water, the

[8] Gill, A. F.: The thermal dehydration or decomposition of certain minerals and salts. Canadian Jour. Res. 10: pp. 703–712, 1934.

[9] Op. cit.

FIG. 2. (Upper) Crushed magnesite grains (−150 + 200 mesh) mounted in liquid of 1.680 index of refraction. Magnification about × 75. Crossed nicols.

(Lower) The same material after conversion to optically anomalous periclase. Mounting media and magnification same as before.

greater proportion was allowed to settle out, and the dust-size material in suspension was decanted. This procedure yields clean fractions which can be easily handled.

Thermal Treatment. These tests were made in a standard muffle furnace of a type available in most chemical laboratories. The temperature of the furnace was controlled simply by the rheostat in the furnace circuit. The proper temperature for selective calcination was obtained by the following trial-and-error method: Two porcelain boats (1 cm. × 5 cm. × 1 cm.) were used, one containing sized magnesite particles, the other sized dolomite particles. These materials were from carefully quartered samples. The boats were placed side by side in the furnace and held at an *indicated temperature* of 550° C. for one hour. The charges were then withdrawn and examined. It was found that neither product had changed. Fresh charges were then placed in the furnace and the resistance changed a little until an *indicated temperature* of roughly 585° C. was attained. The charges were withdrawn at the end of an hour and examined. All the magnesite had been converted to periclase, which exhibited anomalous low-birefringence, and the dolomite was unaffected. It is well to find the temperature range over which the dissociation proceeds as desired. If a thermocouple is not at hand, use can be made of the various positions of the rheostat as a guide to the temperature. In the furnace used, it was found that the temperature of the bottom and the walls was not the same and that it was necessary to support the boats containing the samples on porcelain or a refractory block so that they were not in direct contact with the bottom or walls of the furnace. The reaction time found most satisfactory was one hour. Longer periods of treatment should be avoided.

Microscopic Study. The heated charge was sampled and a small portion mounted on a microscope slide in a liquid with an index of refraction of 1.681. This liquid matches the ω, or higher of the two indices of refraction of dolomite so that it is possible to check the identity of any suspected highly birefringent particles by merely noting whether or not they match. The grains of opaque material, principally iron oxide, were counted first, in

ordinary light. The dolomite and magnesite were then counted under crossed nicols. Minor amounts of silicate and other minerals were neglected.

The decision as to the minimum number of grains to be counted for a given sample is governed principally by the accuracy with which it is desired to know the selected constituent. Dryden[10] has discussed this question adequately and has prepared a graph by which one can determine the minimum number of grains to be counted for a desired accuracy. The large number of grains counted in the minus-200-mesh concentrate was merely done to check the consistency of the data and is not necessary for the desired accuracy. The data given in Table 1 were obtained on some materials resulting from preliminary milling tests and are not to be construed as representative of such tests. They were merely chosen to illustrate the method.

Data.

TABLE 1.

Concentrate (+ *200*)	*Tailings* (+ *200*)
703 grains counted	573 grains counted
Per cent	Per cent
91.4 MgO*	71.4 MgO
8.6 Dolomite	17.8 Dolomite
	10.8 Opaque minerals, etc.
100.0	100.0

* In this and succeeding tables, MgO represents those grains which were originally present as magnesite, but for purposes of determination were dissociated to periclase. In grain counts magnesite and periclase would be numerically identical.

Concentrate (− *200*)	*Tailings* (− *200*)
4168 grains counted	813 grains counted
Per cent	Per cent
91.4 MgO	72.2 MgO
8.6 Dolomite	13.9 Dolomite
	13.9 Opaque minerals, etc.
100.0	100.0

Using the specific gravity given for magnesite and dolomite and assuming the opaque minerals to have a specific gravity equal

[10] Dryden, A. L.: Accuracy in percentage representation of heavy mineral frequencies. Proc. Nat. Acad. Sci. 17: 233–238, 1931. See also, Krumbein, W. C. and Pettijohn, F. J.: Manual of Sedimentary Petrography, 1938. Pp. 470–473.

to 5.2, the percentages above were converted to weight per cent. Using these values and the respective weights of the various fractions, the composition of the combined samples was computed and is given in Tables 2 and 3.

TABLE 2.

COMPOSITION OF THE COMBINED CONCENTRATES PLUS TAILINGS.

	Petrographic data	Calculated from combined chemical data
	Per cent	Per cent
Magnesite	81.8 wt.	82.8 (by difference)
Dolomite	10.0 wt.	8.5 wt.
Opaque minerals	8.2 wt.	8.7 wt.
	100.0	100.0

This is *not* the equivalent of the head sample.

TABLE 3.

COMPOSITION OF THE CONCENTRATES AND TAILINGS.

Concentrates

	Petrographic data	Calculated from combined chemical data
	Per cent	Per cent
Magnesite	93 wt.	92 wt.
Dolomite	7 wt.	6 wt.
Opaque minerals, etc.	Not estimated	2 wt.
	100	100

Tailings

	Per cent	Per cent
Magnesite	70.5 wt.	73.5 wt.
Dolomite	12.9 wt.	11.1 wt.
Opaque minerals, etc.	16.6 wt.	15.4 wt.
	100.0	100.0

The composition of the combined samples was obtained merely as a check on the method. The agreement between the petrographic and chemical methods is satisfactory.

The locking relations (*i.e.*, the intergrowth of the minerals in the fragments)[11] existing between the magnesite and dolomite can be easily investigated on the thermally treated grains. In the samples studied no destruction of the grains by heat was noted. Small amounts of anomalous periclase in fragments, consisting

[11] Faust, G. T. and Gabriel A.: Petrographic methods and their application to the examination of nonmetallic materials. U. S. Bur. Mines. Inf. Circ. 7129: 1–15, 1940.

largely of dolomite or the reverse association, were readily detected.

SOME OBSERVATIONS ON THE OPTICAL ANOMALY OF THE PERICLASE.

The periclase, resulting from the heat treatment at the temperature employed in this study, is optically anomalous in character. It was found that the apparent index of refraction is a function of the duration of the heating. A charge heated at an *indicated temperature* of 605° C. for one-half hour had an index of refraction of 1.615. With longer heating, or at higher temperatures, the index of refraction increases. This is illustrated in Table 4,

TABLE 4.

Index of refraction	Total heating period (hours)	Microscopical notes
1.615	0.5	Anomalous low birefringence. Rhombohedral outline still persists.
1.685–1.690	4.	The rhombohedral outline is being destroyed. The grains still possess a very low birefringence.
1.71 ±	21.5	
1.700–1.705	43	
1.710	65.5	
1.720	89.5	
1.725	209.5	The grains have lost almost all of the birefringence and are essentially isotropic.

which gives the index of refraction of the grains as determined upon charges measured immediately after immersion in the index liquid. If the charge is allowed to stand in the immersion media for several hours, an appreciable increase in the index of refraction of the material results. An X-ray powder diffraction pattern, kindly made by Mr. J. M. Axelrod, confirms the identity of the dissociated material with that of the cubic modification of MgO, periclase. These data indicate that the periclase resulting from the dissociation of magnesite at the temperatures used in this study consists of a skeletal boxwork inheriting the rhombohedral exterior of magnesite. This aggregate is composed of crystallites of periclase and void spaces filled with air. Upon longer heating, this unstable structure collapses. The air is driven out, and as a consequence the index of refraction is raised.

NOTES ON THE STAINING OF THERMALLY-TREATED SPECIMENS.

Fragments of rock, roughly 1″ × 1″ × ¼″ in dimensions and preferably unpolished, were placed in the furnace at the temperature determined in the previous method, and were held there for two hours. Upon removal from the furnace, they were allowed to cool until they could be handled. Thereafter they were stained by immersion in a 5 per cent solution of silver nitrate. Staining took place rapidly and the staining liquid was decanted after two minutes. Examination of the stained specimens under a binocular microscope quickly revealed the amount and distribution of the dolomite. The decomposed magnesite stained black, whereas the dolomite was only slightly discolored. The stain appears to tarnish and is not of permanent value. On one of the stained, decomposed magnesite fragments, a perfect, small "silver tree" growing essentially normal to the surface of the rock was observed.

Recently W. A. Kennedy [12] has differentiated brucite from calcite in brucite marbles by merely heating a fragment over an alcohol lamp for a short time, and then immersing the treated fragment in silver nitrate, whereupon the brucite is stained black and the calcite is unaffected. Brucite decomposes at 400° C. to give periclase, which as previously mentioned, stains readily with silver nitrate.

ACKNOWLEDGMENTS.

The specimens used in this study were kindly supplied by Mr. Willard P. Fuller, Jr., of the Basic Magnesium Incorporated, Luning, Nevada. The manuscript has been read by Drs. C. S. Ross and E. Callaghan and they have also aided in other ways.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
May 14, 1943.

[12] Kennedy, W. A.: Dolomite and brucite-marble in the Scottish Highlands. Geol. Surv. Wartime Pub., No. 6, 1940. With two supplements.

PRODUCTION OF BROKEN LINE PATTERNS WITH STANDARD BEN DAY.

RONALD L. IVES.

ABSTRACT.

Broken line patterns, commonly necessary in geologic and physiographic diagrams, but not available in standard Ben Day sheets, can be produced by the use of standard linear patterns, overlain by various "negative" patterns. Methods of producing broken line patterns are herein described.

INTRODUCTION.

METHODS of using standard art aids—Ben Day applications, multitone papers, and transfer patterns—in geologic and physiographic illustrations were described by Ives in 1939,[1] the methods extended to cover isometric and other block diagrams,[2] and some of the illusion problems connected with the use of composite patterns solved in the same year.[3]

At about the same time, several Government departments, notably the U. S. Geological Survey and the U. S. Department of Agriculture, published diagrams in which these art aids were employed.

Faced with the problem of rapid production of a large number of dissimilar diagrams, Thornthwaite and Stewart-Sharpe developed a carbon transfer process,[4] which, in skilled hands, produces excellent diagrams with a minimum of working time.

By use of the above-described methods, an appreciable fraction of the standard patterns used in geologic diagrams [5] can be applied.

[1] Ives, R. L.: Fabricated diagrams. Jour. Geol. 47: 517–545, 1939.

[2] Ives, R. L.: Shades and screens for isometric block diagrams. ECON. GEOL. 34: 419–436, 1939.

[3] Ives, R. L.: The simple reseau pattern. Psych. Rev. 46: 576–590, 1939.

[4] Thornthwaite, C. W., and Stuart-Sharpe, C. F.: Patterns on maps and diagrams by carbon transfer process. Science 91: 367–368, 1940.

[5] Ridgway, J. L.: Scientific Illustrations. Stanford University, 1938. Plate XXI, p. 122.

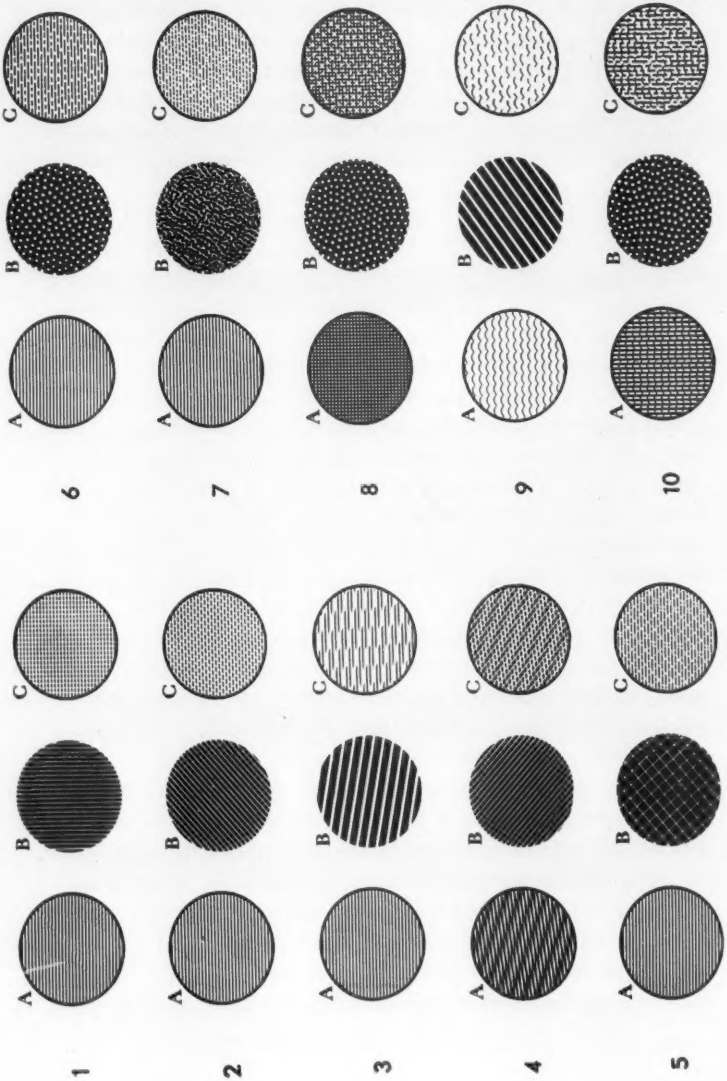

FIG. 1.

Not described in the above-cited works are methods of applying the various patterns used to indicate igneous rocks, and the broken-line patterns used in many types of illustrations.

Recently, one manufacturer [6] has placed on the market two standard "igneous" patterns and one broken-line pattern (similar to 2 C in Fig. 1). Various methods of producing other broken-line patterns by use of standard illustrating aids; and the limitations of these aids, are described.

METHODS OF PRODUCING BROKEN LINE PATTERNS.

A. *Hand Drafting.* Small areas can be given a broken-line pattern by use of a ruling pen and straightedge. This is the standard method in use at present. A highly skilled draftsman can produce patterns similar to 1 C, 2 C, 3 C, or 5 C in Fig. 1. Attempts by ordinary draftsmen usually appear as 6 C or 7 C in the same figure. Were enough skilled draftsmen available, the only serious objection to hand-drawn patterns would be the time consumed in drawing them, and the resultant high cost of the finished drawings.

B. *Negative Retouching.* If a solid line pattern, such as 1 A (Fig. 1), is applied to a drawing, and the whole photographed, the line pattern may be interrupted by retouching the negative with photographer's opaque, or any non-checking ink, such as "celluloid ink." This method is faster than hand-drawing of the entire pattern, but entails considerable skilled and time-consuming work to produce satisfactory patterns. All other factors remaining the same, a person of average skill can produce patterns similar to 1 C or 2 C three times as fast by negative retouching as by direct drawing; and patterns similar to 6 C or 7 C twice as fast. In general, a worker of average skill can produce better patterns by this method than by direct drawing.

C. *Application of Patterns to the Negative.* If any solid line pattern is applied to an original drawing, and the finished drawing

[6] The Para-Tone Co., Inc., 343 S. Dearborn St., Chicago, Ill.

photographed, a large number of interrupted patterns may be produced by applying another pattern to the negative. All patterns of the C series in Fig. 1 can be produced in this manner, the patterns of the A series in the figure being those applied to the drawing, and those of the B series being prints (reversed black for white) of the patterns applied to the negative.

The pattern should be applied to the base (shiny) side of the negative, so that the trimming cuts will not pierce the emulsion and produced unwanted black edge lines. Broken-line patterns of this type can be produced by a relatively inexperienced worker at the rate of 1 linear foot of boundary every ten minutes. Much faster work is possible. Cost of patterning (1943 list prices) is about $1.50 per square foot when all patterns are double—one pattern is applied to the drawing and another to the negative.

The only objection to the two foregoing methods (B and C) is that they necessitate a break in the normal photographic sequence. After the negative is made and dry, it must be worked on before the prints can be made. This is not a serious problem when a good photographic laboratory is adjacent to the drafting room, but is a definite objection when the photographic laboratory is some distance from the office.

D. *Application of Negative Patterns over Positive Patterns.* Reference to the catalogues of most manufacturers of art aids shows that they manufacture most of their listed patterns in both positive—black lines (or red lines which may be photographed as black) on a transparent base, and negative—opaque white lines on a transparent base. By superposing a negative pattern on a positive pattern, a large number, but by no means an infinite variety, of additional patterns can be produced.

A series of patterns made by this method comprises Fig. 1, which is designed to show not only the possibilities but the limitations of the process. Patterns in the A series are the positive patterns. Patterns in the B series, here shown on a black background to permit reproduction, are superposed on the A series. Patterns of the C series are the final result.

USES AND LIMITATIONS OF BROKEN LINE PATTERNS.

A simple calculation will show that more than 10,000 broken line patterns are theoretically possible. Experiments indicate that only about 30 of these, in any one size range, are distinctive enough to be of any practical use. Of these 30, almost half are not suitable because of annoying optical illusions.

Reference to Fig. 1 discloses that patterns 1 A, 2 A, 3 A, 5 A, 6 A, and 7 A are identical. Patterns 1, 2, 3, 5, 6, and 7 C are produced from them, and are certainly not identical, yet of these, only 3 C and one other could be used effectively, in the same size range, on the same drawing. If more were used in the same size range, they would be confused not only with each other, but, if reproduced in small size, with the original line pattern, 1 A. Similarly, 8 A, a cross-hatch, commonly used to indicate an orebody, and 10 A, an irregular cross-hatch (composed of 9 A and a linear pattern similar to 1 A, with the lines vertical), commonly used to indicate cellular structure, are certainly different, but when both are "broken up" by application of a negative random stipple (8 B, 10 B), the resultant patterns (8 C and 10 C) are substantially identical, and could easily be confused.

Where confusion of positive and composite patterns is likely to occur, due to similarity of pattern trends, much or all of the trouble can be eliminated by rotating one pattern so that the general trend makes an angle of 90° with that of the other. For example, if 1 A is rotated 90°, so that the lines are vertical, then 1 A, 1 B, and 1 C could all be used on the same figure with little danger of confusion. Likewise, 4 A and 4 C could be used on the same figure if the reseau trend of one makes an angle of 90° with that of the other, but confusion might result if both trends had the same orientation, as in Fig. 1. Note, however, that 8 C and 10 C would still be similar, and likely to be confused, one for the other, no matter how they are oriented.

It was mentioned above that 1, 2, 5, 6, and 7 C, although of different origin, were so similar that confusion might result. Of this group of patterns, three may be used provided each is of a different size range. For example, if 2 C is made up of pattern

elements twice as large as those comprising 1 C, no confusion will result, and the third pattern should then be made up of elements *four* times as large as the first. If arithmetical, rather than geometrical, size increments are used, "breakdown of discrimination" is likely to occur.

CONCLUSIONS.

Of the four methods described for producing broken-line patterns, one is well known and in common use; all are workable.

Of the three lesser-known methods, that in which a negative pattern is superposed over a positive pattern (Method D) is most suited for general use.

Although a large number of new patterns can theoretically be produced by these methods, only a few—fifteen at most—can be used, in conjunction with standard single patterns, in any one size range.

Confusion between the simpler plain and broken-line patterns, and between various broken-line patterns, can be reduced or eliminated by proper rotation of the pattern trends respective to each other. Confusion between the more complex patterns cannot be so easily eliminated, and omission of the complex patterns is the most logical solution.

By use of any of the methods above described, all of the patterns now in common use in geologic and physiographic illustration can be produced, as well as a few others, useful in special cases.

DUGWAY PROVING GROUNDS,
TOOELE, UTAH,
July 12, 1943.

DISCUSSION AND COMMUNICATIONS

POST-MINE LEACHING OF GALENA AND MARMATITE AT BROKEN HILL.[1]

The discussion submitted by Drs. Stillwell and Edwards [2] is at once helpful and gratifying to the authors. Their contribution deals with two phases of the problem: (1) an additional suggestion for the relative solubility of galena and marmatite, and (2) submission of an alternative explanation for the greater leaching of the northern orebody. With the first we agree in principle, and herewith present recent data which help to substantiate the idea, though the mechanism is not believed to be so simple as indicated by Stillwell and Edwards. Concerning the second suggestion, the original explanation put forward in the paper is held to fit the facts more closely.

Although Garrells' paper [3] had been published, it had not reached Australia at the time ours was written. However in view of the influence which the presence of Cl' ion may have upon the relative solubilities of lead and zinc, as shown by Garrells, it is perhaps worth noting that Broken Hill mine water carries a higher content of Cl' than has been reported from many of the other lead-zinc districts.

Since our paper was published, an analysis of water issuing from the newly-opened northern orebody on the 2,600 ft. level has been made (1/12/43). It is compared with that quoted in the original paper as follows:

[1] Garretty, M. D., and Blanchard, Roland: Post-mine leaching of galena and marmatite at Broken Hill. ECON. GEOL. 37: 365–407, 1942.

[2] ECON. GEOL. 38: 253–254, 1943.

[3] Garrells, R. M.: The Mississippi Valley type lead-zinc deposits and the problem of mineral zoning. ECON. GEOL. 36: 729–744, 1941.

	2,450-ft. Level.	2,600-ft. Level.
Total solids in solution	878 grs./gallon	836 grs./gallon
Pb	nil grs./gallon	0.02 grs./gallon
Zn	28 grs./gallon	1.5 grs./gallon
Mn	20.6 grs./gallon	1.4 grs./gallon
Fe	nil grs./gallon	trace grs./gallon
Mg	? grs./gallon	24.3 grs./gallon
Ca	? grs./gallon	60.6 grs./gallon
F	nil grs./gallon	nil grs./gallon
Al_2O_3	? grs./gallon	0.7 grs./gallon
SiO_2	? grs./gallon	1.6 grs./gallon
SO_3	400 grs./gallon	220.6 grs./gallon
CO_2	nil grs./gallon	3.4 grs./gallon
pH value of water	6.4 grs./gallon	7.3 grs./gallon
Concentration of Cl′	0.066 molar	0.104 molar

Increasing importance of lead relative to zinc in the second analysis is significant, and affords corroboration for the explanation offered by Stillwell and Edwards. The explanation is not, however, wholly satisfying.

In their discussion Stillwell and Edwards, referring to Garrells' paper, state "the presence of Cl′ ions in Pb-Zn solutions, in concentrations in excess of 0.1 N, rendered the zinc less soluble than the lead." On that basis, in view of general uniformity of the leaching over widespread areas within a brief space of time, and because salinity of the mine water is general, any change for the Northern orebody as a unit should be reflected in retention of zinc and exportation of lead. The evidence however, as noted in our paper (pp. 158–159), points to retention of the dissolved lead within the limits of the orebody, and exportation of zinc therefrom in possibly substantial amount.

In that connection our reading of Garrells' paper differs somewhat from that of Stillwell and Edwards. Garrells' findings appear to be:

> . . . the addition of sodium chloride to a solution of lead and zinc first increases the solubility of both metals until the solution becomes 0.1 molal in chloride, but above 0.1 molal the lead continues to increase in solubility, while zinc rapidly decreases. . . . This means that, if the vein solutions contained 2.0 molal or more concentrated chloride, the zinc ion activity would be so increased, and the lead ion activity so depressed, that sphalerite would precipitate from such a solution before galena.

Furthermore, the data quoted refer to a temperature of 100° C., whereas at the North mine the temperature would scarcely exceed 40° C., and (p. 738)

"the effect is greater at higher temperatures, approximately doubling with temperature changes from 25° C to 65° C." [4]

Assuming that the effect is no more than halved (probably an understatement) by a drop from 100° C. to 40° C., would not the concentration of chlorine required in the circulating waters be at least 4 molal, or nearly 10,000 grains per gallon? Such concentration at Broken Hill, to bring about uniform effects over so widespread an area of attack, seems quite improbable.

The mechanism suggested by Stillwell and Edwards throws much light upon an admittedly complex problem. Presumably the same general combination of constituents is tending to bring about, in dilute solution and under supergene conditions at Broken Hill, the effects noted by Garrels as capable of bringing them about in hot and concentrated solutions during hypogene ore deposition in the Mississippi Valley. This encourages the hope, expressed in our paper, that when eventually more detailed experimental work is done on the chemistry of the various solution complexes, the full mechanism of solution and precipitation, to explain the abnormal leaching effects at Broken Hill, will become clear.

Concerning the preferential leaching of Northern orebody ore, Stillwell and Edwards, in rejecting our speculation for another, appear to have been misled by the undisputed fact that the Northern orebody overlies the Southern orebody in cross section. In deducing that the "groundwaters must be drained from the Northern orebody before the Southern orebody" they overlook, however, the sequence of mining operations, whereby the orebodies are developed in horizontal levels and not vertical sections. On any one level the waters are drained first from the Southern orebody. As shown by the dashed contours of Fig. 2 in the paper, and explained in the text, the final draining of water from

[4] Garrels: op. cit., pp. 739–740.

the Northern orebody on any level may post-date by several years the draining of the Southern orebody. Since Stillwell and Edwards agree that the leaching is brought about by circulating groundwater they must, to be consistent, allow that wholesale leaching of the Northern orebody at any point will cease with the lowering of the zone of circulation below that point. If leaching were dependent on simple vertical extension of the orebodies in cross sections, it should be not virtually confined to the Northern orebody but be gradational from upper to lower limits of the lode —not only in the North mine but also in the other mines of the district. It must also be emphasized that the leaching appears to be complete by the time developmental openings expose the ore. The claim that the upper orebody is leached preferentially because surface waters reach it first, and have not yet become saturated with dissolved minerals and neutralized by the carbonate gangue is not convincing, even if we neglect the points mentioned above. If carbonate gangue reduced the leaching power of the solutions, then surely the Northern orebody, with its carbonate gangue, should have been leached less than the Southern orebody, with siliceous or rhodonitic gangue.

M. D. Garretty,
Roland Blanchard.

Broken Hill,
New South Wales,
Mount Isa,
Queensland,
August 18, 1943.

REVIEWS *

Tungsten: Its History, Geology, Ore Dressing, Metallurgy, Chemistry, Analysis, Applications, and Economics. By K. C. LI AND CHUNG YU WANG. Pages xvii + 325. Reinhold Publishing Corporation, 330 West Forty-second Street, New York, U. S. A., 1943. Price, $7.00.

This volume on tungsten is No. 94 in the American Chemical Society Series of Scientific and Technologic Monographs, which are designed to serve the double purpose of presenting intelligibly the available knowledge on a chosen topic to workers in other fields and to stimulate further research by such a survey of the progress already achieved. The broad scope of the present monograph is fully indicated by the subtitle selected.

In an interesting Foreword by the senior author he recounts how, in 1911, he came to make the first discovery of tungsten ore in China. It was by accident, he modestly says, but the event illustrates again the dictum of Pasteur that such accidents happen only to the prepared mind. In 1915 China shipped her first tungsten concentrate, consigned to the United States. The original discovery of tungsten ore, wolframite, had been made in Hunan Province, but soon afterward tungsten ore was found in the provinces of Kiangsi, Kwantung, Kwangsi, and Yunnan. Since 1915 China has been the leading producer of tungsten ore and her output has dominated the world's markets. Kiangsi has proved by far to be the most productive: tungsten deposits have been found throughout an area of 14,000 square miles and 80 localities are being worked; they produce about 70 per cent of the total output of China. Contrary to the oft-repeated assertion, the tungsten concentrates are not won from stream placers; but eluvial deposits consisting of hillside mantle detritus are common. The detrital deposits appear to be already worked out, and production is now largely or entirely from bedrock deposits.

Chapter II on the geology of tungsten gives an excellent picture of the world's tungsten deposits. The classification adopted in describing the deposits is that of Lindgren. Replacement deposits are said, on page 16, to be of no consequence, but later, on page 58, the scheelite-bearing con-

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

tact-metamorphic deposits of the western United States, which are replacement deposits of a very individual stamp, are shown to be of great importance; but this lapse of logic is common with many other authorities on economic geology. The chapter concludes with an estimate of the tungsten resources of the world. The authors admit that estimates of ore reserves in general, and tungsten in particular, "are more or less guesswork," chiefly more so, one must recognize. For China the Geological Survey of Kiangsi has estimated reserves of 4,400,000 short tons carrying 60 per cent WO_3, and F. L Hess has estimated that the resources of the remainder of the world, as of 1938, amount to 277,000 tons. The outstanding position of China is clearly indicated.

The succeeding chapters deal with the technology of tungsten—ore dressing, metallurgy, chemistry, analysis of ores, industrial applications, possible substitutes for tungsten, and the economics of tungsten. These topics are all treated in lucid language, and the usefulness of the volume is increased by the valuable bibliographies appended to the successive chapters.

ADOLPH KNOPF.

Chemical Spectroscopy, 2nd Edit. By WALLACE R. BRODE. Pp. xi + 677; Figs. 354; Pls. 40. John Wiley and Sons, New York: Chapman and Hall Ltd., London, 1943. Price, $7.50.

Geologists intending to apply spectrographic methods to their work or those interested in interpreting and evaluating spectrographic investigations in the field of geology will find "Chemical Spectroscopy" by Professor Brode extremely useful. Such persons must of course have a background of general physics and chemistry.

The volume is intended as an introductory textbook and a source of spectroscopic information. The organization of chapters is the same as in the first (1939) edition; however, new material has been added and its presentation improved. Chapters of special interest to geologists, metallurgists, and analysts include those on emission spectra apparatus, qualitative and quantitative analysis, photography, and laboratory arrangement. Material on absorption spectra, resonance and chemical structure which is of more interest to organic chemists comes in separate chapters. A series of twelve laboratory exercises is provided for instruction in technique and demonstration of theory. There is a good bibliography of books and publications on spectroscopy and a limited list of research papers. The 260 pages of spectrum tables and charts and conversion tables in the last half of the book enhance its value as a laboratory manual.

HARRY MIKAMI.

Hydrocarbons of the Uinta Basin of Utah and Colorado. By CLARK F. BARB AND JAMES O. BALL. Pp. 115; Figs. 19; Pls. 2. Colorado School of Mines, Quarterly, Vol. 39, No. 1. Golden, 1944. Price, $1.50.

In the Uinta Basin the Tertiary beds—Wasatch, Green River, Bridger, and Uinta—contain many interesting hydrocarbons. The profusion and variety of these hydrocarbons make the area unique and it is interesting to note that the containing beds have been considered to be of fresh-water origin. The beds of this topographic and structural basin are not clearly understood and part of the confusion results from unconformities which lie at the base of the Tertiary and at the top of the Green River beds. The hydrocarbons, except for a few coal seams, seem to be restricted to the Tertiary and are believed by some to have originated from a common mother material in these beds.

The bitumens albertite, gilsonite and wurtzilite occur in veins throughout the region and are commercially exploitable. Vast deposits of bituminous sands ("tar sands") are available for open-pit removal. This material has been used locally for roofing and for highways. The great reserves of coal and extensive oil shales of the basin are well known. Although very little oil and gas have been found in the basin, the possibility exists that productive structures may be found in the underlying Cretaceous formations. At a time of rapidly diminishing petroleum reserves the Uinta Basin is an area to keep in mind.

In this very interesting publication, Barb, Professor of Petroleum Engineering at the Colorado School of Mines, thoroughly describes the occurrences of bituminous sands in the basin as well as their mining and marketing. In the discussion he refers to numerous geologic publications concerning the topic, but his personal acquaintance of the area is clearly brought out in the text.

The last 43 pages of the paper contain a survey of bitumen analyses and extraction methods. This section is written by J. O. Ball, also of the Colorado School of Mines. Each of the hydrocarbon forms in the basin is fully described with regard to physical and chemical properties. Numerous tables present statistical data. Both sections contain large bibliographies. Accompanying maps show locations of known hydrocarbon deposits and surface geology of the area.

RALPH E. DIGMAN.

Mineral Resources of Minnesota. Edited by W. H. EMMONS AND F. F. GROUT. Pp. 149; Figs. 25. Minn. Geol. Surv. Bull. 30. Minneapolis, 1943.

Florida Mineral Industry. By ROBERT O. VERNON. Pp. 207; Figs. 40. Florida Geol. Surv. Bull. 24. Tallahassee, 1943.

Since the publication of Bulletin 624 (1917) of the U. S. Geological Survey, *Useful Minerals of the United State,* many of the states have issued independent descriptions of the minerals and mineral industries of their own areas. Each of these has been written by geologists thoroughly acquainted with the mineral situation of the state and each was a valuable contribution to the literature of economic geology. The two publications discussed in this review are certainly no exceptions.

The Minnesota bulletin was written by Grout, Gruner, Schwartz, Stauffer, and Thiel. Following a section on the geology of the state, 44 pages are devoted to the valuable iron deposits in central and northeastern Minnesota. Each of the individual iron ranges—Cayuna, Mesabi, Vermillion, and Gunflint—is described and the titaniferous magnetite deposits in or near the Duluth gabro mass are discussed. History, technology, economics, and future of Minnesota's iron mining are considered. The deposits of manganese, peat, and miscellaneous nonmetallic minerals of the state are discussed as are the occurrences of building stones and clays.

In his paper on the mineral industries of Florida, Vernon includes production data of Florida's minerals for 1940 and 1941. He describes the geology of the state including structure and stratigraphy of the formations observed and typical land forms. Oil and gas possibilities are considered and wildcat wells listed. The cement industry in the state is discussed and considerable space is devoted to the phosphate deposits and to the removal and treatment of this material. Other resources of the state here discussed include: pigments, clays, diatomite, peat, crushed stone, flint, limestone, and shells. A bibliography and a directory of Florida mineral producers are appended. Many excellent halftones are included.

BOOKS RECEIVED.

RALPH E. DIGMAN.

Pan American Economics. By PAUL R. OLSON AND C. A. HICKMAN. Pp. 479; Figs. 21. John Wiley & Sons, New York, 1943. *"The purpose of this book is to explore the economic life of Latin America." One important phase of such an exploration lies in the study of the mineral resources of Central and South America. Chapter 6 of this fine book is entitled Latin America Outlets for Investment, and it is here pointed out that huge foreign investments have been made in the deposits of petroleum, copper, gold, silver, tin, manganese, and others, which exist south of the Rio Grande. Although the accessible ores of the precious metals have been thoroughly exploited, "untapped reserves and future potentialities seem greatest in the more prosaic,*

modern minerals." Emphasis is placed on petroleum and iron ore, and reserve figures are given for these.

Maps and Survey. By ARTHUR R. HINKS. 4th Edit. Pp. 300; Pls. 28. Cambridge University Press, London, 1942. *This book was first published in 1913 as an introduction to the study of maps and the processes of survey by which they are made. The history of map-making is reviewed and descriptions of modern maps are presented with emphasis on British Official maps and European maps. An annotated list is included of many available maps of the Geographical Section of the British General Staff, and of many geographical societies outside Great Britain. The second part of the book deals with surveying methods, instruments used, and aerial photography. Unfortunately, the various methods of map projection are not discussed.*

U. S. Geological Survey. Washington, 1943.

Bull. 928–C. **Adsorbent Clays, their Distribution, Properties, Production, and Uses.** P. G. NUTTING. Pp. 90; Figs. 25; Pl. 1. Price, 20 cents.

Bull. 928–D. **Manganiferous and Ferruginous Chert in Perry and Lewis Counties, Tennessee.** E. F. BURCHARD. Pp. 50; Fig. 1; Pls. 15. Price, 25 cents.

Bull. 939–D. **Geophysical Abstracts 111, October–December, 1942.** W. AYVAZOGLOU. Pp. 39. Price, 10 cents.

Bull. 940–B. **Manganese Deposits of the Elkton Area, Virginia.** PHILIP B. KING. Pp. 40; Figs. 4; Pls. 5. Price, 75 cents.

Bull. 940–C. **Geophysical Surveys in the Ochoco Quicksilver District, Oregon.** E. L. STEPHENSON. Pp. 4; Figs. 3; Pls. 9. Price, 50 cents.

Prof. Paper 205–A. **Relative Abundance of Nickel in the Earth's Crust.** R. C. WELLS. Pp. 19; Figs. 4. Price, 10 cents.

A Process for Extracting Alumina from Kansas Clay. E. D. KINNEY. Pp. 22. Kansas Geol. Surv. Bull. 47, Pt. 4. Lawrence, 1943.

Geology and Ground-Water Resources of Hamilton and Kearny Counties, Kansas. T. G. MCLAUGHLIN. Pp. 220; Figs. 18; Pls. 17. Kansas Geol. Surv. Bull. 49. Lawrence, 1943.

Water Flooding of Oil Sands in Illinois. F. SQUIRES AND A. H. BELL. Pp. 101; Figs. 76. Illinois Geol. Surv. Rept. Invest., No. 89. Urbana, 1943.

Clay County. H. R. BERGQUIST, T. E. MCCUTCHEON, AND V. H. KLINE. Pp. 188; Figs. 14; Pls. 7. Mississippi Geol. Surv. Bull. 53. University, 1943.

Carbonizing Properties and Petrographic Composition of Thick Freeport-Bed Coal from Harmar Mine, Harmarville, Allegheny County, Pa., and the Effect of Blending this Coal with Pocahontas No. 3- and No. 4-Bed Coals. J. D. DAVIS AND OTHERS. Pp. 46; Figs. 24. U. S. Bureau of Mines, Tech. Pap. 655. Washington, 1943. Price, 10 cents.

Production of Industrial Explosives in the U. S. during the Year 1922. W. W. ADAMS AND V. E. WRENN. Pp. 24; Figs. 2. U. S. Bureau of Mines, Tech. Pap. 658. Washington, 1943. Price, 10 cents.

Cronica Bibliografica. A. CASTELLANOS AND P. PASOTTI. Pp. 166. Inst. de Fisiog. y Geol. No. 36 (IV). Rosario, Argentina, 1943.

El Estusio de los Cristales en el Espectro Infra-rojo. A. LEVIALDI. Pp. 15. Inst. de Fisiog. y Geol. XV. Rosario, Argentina, 1943.

Construccion de un Radiometro Diferencial para Espectroscopia en el Infra-rojo. A. LEVIALDI. Pp. 14. Inst. de Fisiog. y Geol. XVI. Rosario, Argentina, 1943.

The Diamond Deposits of the Gold Coast with Notes on Other Diamond Deposits in West Africa. N. R. JUNNER. **The Crystal Form of Diamonds from the Gold Coast.** F. A. BANNISTER. Pp. 52; Pls. 7. Gold Coast Geol. Surv. Bull. 12, 1943. Price, 3 s. *This excellent description of the diamondiferous areas of west Africa was written by the director of the Gold Coast Geological Survey. In his account, the author discusses the two chief diamond fields of the Gold Coast, the Brim and the Bonsa, in a very thorough manner and, more briefly, describes other deposits in the Gold Coast and other west African regions. Hypotheses to account for the origin of the diamonds are discussed as are grading and valuation and industrial uses of diamonds. An appendix on the crystal form of Gold Coast diamonds (by Bannister) and several maps of the areas discussed are included. The literature on this important district has been quite inadequate and this paper is an outstanding contribution.*

Ground Water in the Oil-Field Areas of Ellis and Russell Counties, Kansas. J. C. FRYE AND J. J. BRAZIL. Pp. 104; Figs. 9; Pls. 2. Kansas Geol. Surv. Bull. 50. Lawrence, 1943.

The Stratigraphy and Structural Development of the Forest City Basin in Kansas. WALLACE LEE. Pp. 142; Figs. 22. Kansas Geol. Surv. Bull. 51. Lawrence, 1943.

Mining Industry of Idaho for the Year 1943. ARTHUR CAMPBELL. Pp. 251. 45th Annual Report of Inspector of Mines. Boise, 1944.

Nineteenth Biennial Report. W. C. MORSE. Pp. 11. Mississippi Geol. Surv. University, 1943.

SOCIETY OF ECONOMIC GEOLOGISTS

REPORT ON THE ACTIVITIES OF THE DIVISION OF GEOLOGY AND GEOGRAPHY OF THE NATIONAL RESEARCH COUNCIL 1942–1943.

The annual meeting of the Division was held May 1, 1943, at 2101 Constitution Avenue, Washington, D. C. The morning session was devoted to a general survey of geologic and geographic activities in war work. Descriptions of various phases of the work were given by representatives of the War Agencies and Armed Forces. The subjects covered four fields— (1) strategic minerals, (2) geologic engineering advice to the Armed Forces, (3) reports on the physical characteristics and raw materials of strategic areas, and (4) interpretation of aerial photographs and maps. As most of the reports were more or less confidential, no written records of the reports or discussions were permitted. The purpose was to help in obtaining contacts, materials, or men for particular needs, and to bring out new ideas about utilization of groups or individuals not directly engaged in war work.

The direct participation of the Division in war work was very much limited. Nearly every geographer of adequate experience has been drawn into the technical services of the Armed Forces and War Agencies. On the other hand, the major utilization of geologists in the search for strategic minerals and sources of oil and gas has been in Federal, State, or private organizations. The Division contributed chiefly in advice on special topics and in doing minor tasks that were requested.

The War Projects and War Effort Committees of the Division and of the Geological Society of America continued work in cooperation. The N. R. C. special projects were handicapped by loss of personnel and facilities to those organizations engaged in essential work. The first annual supplement to the Bibliography of Military Geology and Geography was issued by the G. S. A. as the result of cooperative efforts. A committee on map presentation of physical features worked on physiographic maps of special areas of military importance.

The regular committee work of the Division was also considerably curtailed. The Committee on Problems of Ore Deposits was inactive for a second year, but a number of other committee projects of general interest were continued. The Committee on Tectonics carried to completion the tectonic map of the United States, which is now in first proof. The Glacial map of North America is also in advanced stages of reproduction.

In addition to the above, economic geologists will be interested in the following items, either completed or in preparation by Divisional committees.

Ore Deposits as Related to Structural Features (Divisional Committee on Processes of Ore Deposition) published in book form late in 1942 by the Princeton Univ. Press.

Stratigraphic Correlation Charts (Divisional Committee on Stratigraphy) published by G. S. A. as completed.

Measurement of Geologic Time (Divisional Committee). Yearly mimeographed report and annotated bibliography.

Deformation of Ross Ice Shelf (Divisional Committee), a structural study of complex fault and fold patterns. In preparation.

1st Annual Supplement to Bibliography of Military Geology and Geography (G. S. A. and Division), issued and distributed by G. S. A.

Manual for Self Instruction in Mapping from Aerial Photographs (Divisional Committee). In progress.

W. S. BURBANK,
Representative,
Society of Economic Geologists.

HIGH-ALUMINA CLAY IN PENNSYLVANIA.

RICHARD M. FOOSE.

Diaspore occurs in association with flint clay at the Mercer horizon underlying two large districts in Clearfield County, Pennsylvania. The diaspore occurs as nodules of various size in the flint clay and there are all gradations between flint clay and almost pure diaspore. The deposits are usually lenticular, and are apparently related to the structure of the underlying Connoquenessing sandstone.

The areal distribution, physical character and structural relations, and the petrography of the diaspore-bearing clays are described.

FLOW OF GRANULAR PRODUCTS THROUGH BINS.

SAMUEL M. SHALLCROSS.

The author has determined experimentally and empirically the direction and rate of flow of any particle at any location in bins. The rate of flow has been reduced to geometrical formulæ based on the coefficient of friction of the product and, therefore, they are applicable to any material which has a reasonably constant coefficient of friction.

These laws of the direction and rate of flow are necessary to the miner to locate properly the withdrawal chutes of a shrinkage stope with respect to the footwall and, to a minor degree, to locate distances between withdrawal chutes.

It is in industrial plants, however, that the need for complete understanding of these laws is greatest. The descent of the charges in blast furnaces, lime shaft kilns, preheaters, soaking pits (for granular materials), vertical shaft coolers, all follow these laws.

Graphical methods for solving simple problems are described and some practical applications of the laws are given by way of illustration.

THE EXPLORATION OF FIVE WESTERN CLAY DEPOSITS.

NORMAN L. WIMMLER

WITH THE COLLABORATION OF

H. G. IVERSON, S. H. LORAIN, P. E. OSCARSON, AND S. RICKER.

As a result of extensive investigations of high alumina clay deposits in the Western United States, the U. S. Bureau of Mines conducted detailed exploration of the Molalla and Hobart Butte deposits in Oregon, the Cowlitz-Castle Rock deposit in Southwestern Washington, the Olson deposit in Idaho, and the Ione deposit in California. Other deposits were given preliminary scout drilling. This paper deals mainly with the

general procedure and the methods employed and records the pertinent details of the results obtained.

The various drilling methods, and the sampling and analytical procedures are briefly described. Drilling data are given in a table. A total of 738 holes for a footage of 49,367 feet were drilled in the areas listed.

These five major deposits within their explored limits are estimated to contain 174,714,000 natural or wet tons of measured clay and 52,928,000 tons of indicated clay ranging from 23.5 to 30 per cent in available alumina on a dry basis. Clays of similar quality and probably in greater quantity can be reasonably inferred to exist in areas adjoining or adjacent to those explored. Estimates of the overburden, and of the clay reserves with their average analyses in available alumina and ferric iron, and other data for each deposit, are recorded in table form.

These deposits are favorably situated for low cost open cut mining methods but as year round operation will be required, special preparation and procedure will be essential to lessen the handicaps which the rainfall of the winter season can create. The removal of overburden should be confined to the dry season. The mining of the clay can apparently best be done by power shovels, with trucks, belt conveyors, or railroad cars as means of transportation to the plant. The combined cost of preparation for overburden removal and for mining the clay is estimated at from 20 to 30 cents per ton with a small variation probable.

This exploration has proven ample quantities of clay, suitable for the production of alumina, to be available in each of these major deposits. Numerous other deposits located within reasonable distances from them can be considered contributory sources of large additional quantities of similar clay. The five deposits are favorably situated for low cost open pit mining, and are well located in respect to available transportation routes, to localities affording suitable facilities for the production of alumina, and to the alumina reduction plants.

A pilot plant of proper capacity and with necessary facilities should be established in the Pacific Northwest to prove definitely the metallurgical processes and the economics of producing alumina from these clays.

BLOCK TALC.

J. E. EAGLE.

Massive steatite, or block talc, is defined and described; occurrence, mining and processing are discussed, historical uses as pottery material based on ease of forming and vitrification properties are traced, also modern uses as insulating material for electrical equipment.

SCIENTIFIC NOTES AND NEWS

E. B. MATHEWS, treasurer of the Geological Society of America since 1917, died on February 4, at the age of 74 years. He was a member of the staff of the department of geology of the Johns Hopkins University since 1894, was professor of mineralogy and petrography from 1904, and chairman of the department of geology from 1917 until his retirement in 1939. Professor Mathews was also assistant state geologist of Maryland from 1896 to 1917 and state geologist from 1917 to his retirement in 1943.

H. S. MCQUEEN, formerly assistant state geologist of Missouri, has joined the geological staff of the Republic Mining and Manufacturing Company, exploration and mining subsidiary of the Aluminum Company of America. He will be located at 230 Park Avenue, Room 2535, New York 17, New York.

H. A. MEYERHOFF has been elected vice-president, representing geology and geography, and W. E. WRATHER to the executive committee of the American Association for the Advancement of Science.

W. A. ATWOOD, president of Clark University, has been given the Distinguished Service Award of the National Council of Geography Teachers "for his persistent efforts to advance geography . . . and his establishment and editorship of *Economic Geography* since 1925."

H. R. ALDRICH, C. H. BEHRE, JR., K. C. HEALD, A. I. LEVORSEN and W. B. HEROY have been appointed members of a committee on geological personnel of the National Research Council, Division of Geology and Geography, effective July 30, 1943. The purpose of the new committee is to survey, plan and coordinate the activities in personnel matters of the various societies, institutes, foundations and other agencies in the field of geology.

A. J. TIEJE, professor of geology at the University of Southern California, died on January 25 at the age of 52 years.

S. G. BLAYLOCK, president and managing director of the Consolidated Mining and Smelting Co. of Canada, Ltd., was made an honorary member of the A. I. M. E. at the annual meeting in February.

F. H. LAHEE, chief geologist of the Sun Oil Co., Dallas, Texas, has been appointed official representative of the A. A. P. G. to the meeting of the Petroleum Industries War Council and the Petroleum Administration for War.